WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Newman Lake

Total Phosphorus
Total Maximum Daily Load

Water Quality Improvement Report

Draft

June 2006
Publication Number 06-10-045

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Water Quality Program

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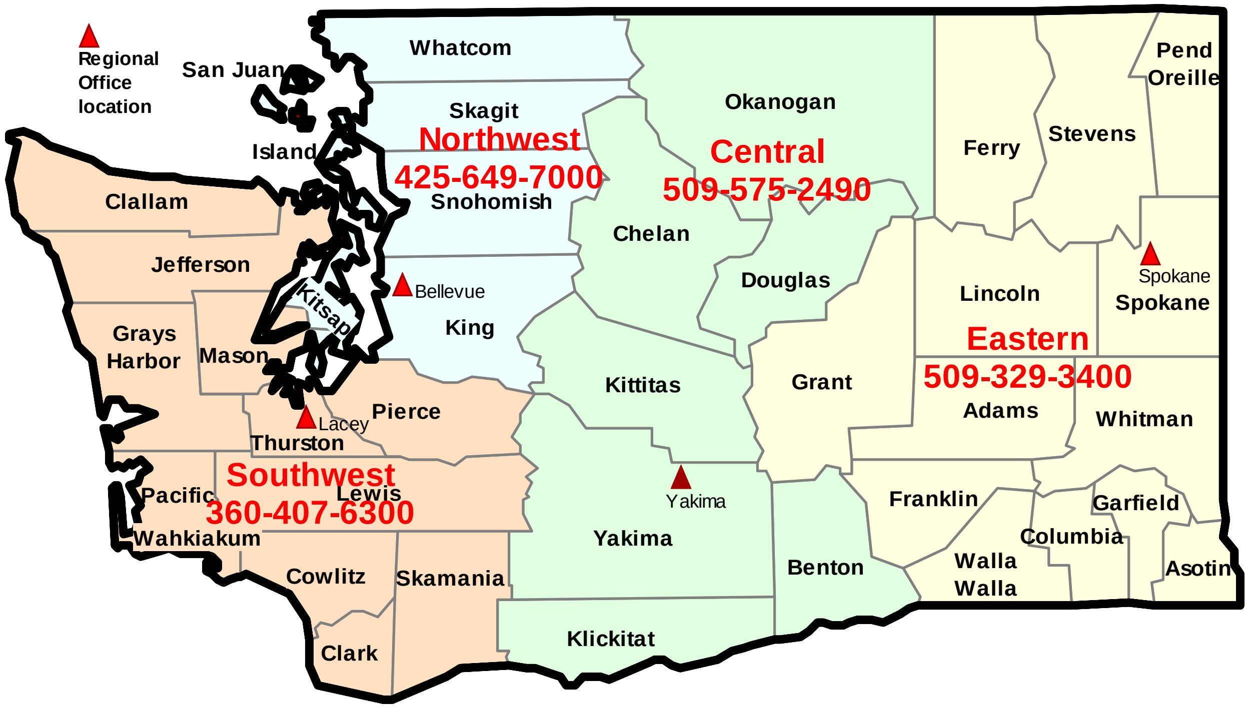

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Summary

The water quality of Newman Lake, located ten kilometers northeast of Spokane, Washington, has been a focus of interest for over thirty years. During this period, several studies have been conducted by Washington State University's (WSU) Water Research Center and activities implemented by state and local governments and concerned citizens directed at both understanding and ultimately improving the lake's water quality. Much of this work was initiated due to community concerns regarding deteriorating water quality as indicated by high algae growth.

In lakes, among the most evident effects to water quality from increased availability of the nutrient phosphorus is elevated growth of algae during the summer months. Excessive algae growth reduces water clarity, results in chronic increased oxygen demand in the bottom sediments, severely impacting coldwater aquatic habitat and can, depending on the dominant algae present, pose a human health risk. Historically, Newman Lake has experienced toxic blue-green algae blooms in 1983 and again in 1985. The mechanism triggering toxic blue-green algae growth is not fully understood through an environment with an elevated supply of phosphorus tends to favor the dominance of blue-green algae in relation to other types of phytoplankton.

For this reason, initial water quality investigations of Newman Lake (1986), conducted by WSU, focused on quantifying phosphorus sources both within the lake, associated with sediments (internal sources) and those external to the lake such as surface water runoff. The results of that work indicated that the release of phosphorus from sediments during the summer was the primary source stimulating the algae growth. To reduce this source, a whole lake alum treatment was conducted in 1989 and a hypolimnetic aerator installed in 1992. In 1997, the aerator was modified with an alum injection system.

The water quality data collected as part of the initial investigation and subsequent work led to Newman Lake's inclusion on Washington State Department of Ecology's 1996 and 1998 303(d) lists for total phosphorus. Section 303(d) of the federal Clean Water Act requires that states compile a list of surface water bodies impacted by pollutants, such as total phosphorus, where uses such as water supply, fishing, swimming, and boating are impaired. Once a water body is on the 303(d) list a total maximum daily load (TMDL) study is required.

This TMDL addresses impairment of Newman Lake's characteristic uses and aesthetic qualities caused by the nutrient phosphorus. It examined the pathways that phosphorus is introduced to the water column of Newman Lake. By understanding and quantifying these pathways, limits or allocations were defined on the amount of phosphorus that can be introduced to the lake in order to constrain algae growth. The underlying strategy is that algae growth can be controlled by limiting the introduction of phosphorus.

Lakes can be characterized by their level of biological productivity, or trophic state. A lake's natural level of productivity is determined by factors such as its geologic setting, watershed size and relief, bathymetric characteristics, climate, and the quantity and quality of the water entering

and leaving the lake. Increases in a lake's productivity over time, known as eutrophication, is a natural process though for many lakes such as Newman Lake this process has been accelerated by human-related activities. Surface and groundwater inflow associated with nonpoint pollution sources such as residential development and maintenance, agricultural, and forestry are a few of the pathways present in the Newman Lake drainage area that contribute phosphorus either directly to the lake or to inflowing surface waters ultimately resulting in an increase in the lake's productivity.

In order to establish limits on phosphorus sources, an expectation of the maximum summer period phosphorus concentration for Newman Lake was first required. The target concentration is reflective of a condition where phosphorus sources are managed resulting in the restoration of the lake's characteristic uses. A target summer period concentration of 20 micrograms per liter (ug/L) was set based on providing a 90 percent assurance that this recommended level for lakes situated within the Rocky Mountain eco-region, the setting of Newman Lake, is achieved in any given year. The target concentration is defined as the median concentration observed during the summer period, June through August, within the upper water column (epilimnion), 0 to 3 meters below the water surface. The target was defined for the summer period because this is when environmental conditions favor algae growth coinciding with peak recreational use of the lake.

Central to the TMDL analysis are the determination of the load capacity and load allocations. The load capacity is defined as the maximum amount of total phosphorus that can be introduced to the upper water column (epilimnion) from September to the following August while maintaining concentrations at, or below, the target concentration, 20 ug/L. Once defined, the load capacity is apportioned among the major phosphorus sources through the setting of load allocations. Load allocations were set for phosphorus sources that are observed at excessive levels though where some control is possible. A margin of safety must be considered throughout the analysis process so that when the allocations are achieved the lake's water quality will have improved to a level where all previous characteristic uses are restored.

During the analysis process, a phosphorus budget was constructed quantifying the amount of phosphorus introduced to the water column from various sources while also examining when the introductions occurred. Total phosphorus (TP) sources to Newman Lake can be divided into two categories: those internal to the lake, primarily through the release of TP from sediments under anaerobic conditions and those external to the lake such as TP present within surface water inflow. The external sources considered as part of this analysis include: precipitation, surface water inflow, and on-site wastewater systems.

The focus of this TMDL is on establishing limits to external phosphorus sources due to the fact that management measures to control in-lake phosphorus recycling are currently in place and that the concentration of phosphorus observed in the upper water column of Newman Lake is closely related to the level of external loading. This study assumes that over time, with control of external phosphorus sources, the impact to water quality from internal sources will also decline. For now, the load allocation for phosphorus associated with internal recycling was set to the annual (September through August) median level observed over the analysis period (1991-2004). Further reductions to achieve the target concentration will come from reductions in external sources.

Analysis results indicate that in order to meet the 20 ug/L target concentration, a 40 percent reduction in September to August external loading is required. Both the loads and concentrations are based on median levels observed from 1991 to 2004. The load capacity has been set at 985 kilograms; 702 kilograms attributed to external sources and 283 kilograms attributed to internal sources, September through August. The external sources examined by this study included Thompson Creek, watershed drainage (exclusive of Thompson Creek), precipitation, and on-site wastewater treatment systems. A 40 percent reduction in external TP loading results in a 90 percent assurance the target concentration will be achieved in any given year while providing a 50 percent assurance that summer phosphorus concentrations will remain below 17 ug/L. In comparison, without reductions in external loading, the 90^{th} and 50^{th} percentile concentrations predicted by the model over the period 1991 to 2004 are 30 ug/L and 26 ug/L, respectively.

The load capacity was achieved by reducing median summer period loading for Thompson Creek, watershed drainage, and on-site systems by 40 percent.

Based on historic relationships of phosphorus concentrations as they relate to chlorophyll (a), an indicator of algae growth, and Secchi depth, an indicator of water clarity, the achievement of the target concentration will decrease chlorophyll (a) concentrations to approximately 6 ug/L, resulting in an increase in water clarity by 1-meter.

Introduction

Overview of the Total Maximum Daily Load Study Process

The federal Clean Water Act (CWA), requires each state to establish water quality standards to protect, restore, and preserve water quality. These standards have been set to protect designated uses such as drinking water supplies or cold water habitat, critical to the survival of certain organisms. Criteria, usually numeric, are used as a gauge to achieve those uses. When a lake, river, or stream fails to meet water quality standards, after application of technology-based pollution controls, Section 303(d) of the CWA requires that states include it on a list of impaired water bodies and prepare an analysis called a **total maximum daily load** (TMDL). The United States Environmental Protection Agency (EPA) has established regulations (40 CFR 130) and developed guidance for establishing water clean up plans (EPA, 1991).

Through the TMDL analysis, a **loading capacity,** or the maximum amount of a given pollutant that can be discharged to a water body, while still meeting water quality standards, is determined. That load capacity is allocated among the various sources responsible for the pollution problem. If the pollutant originates from a discrete source (point source) such as an industrial facility's discharge pipe, that facility's share of the loading capacity is called a **wasteload allocation**. If the pollutant originates from a diffuse source (nonpoint source) such as runoff from an agricultural operation, that facility's share is called a **load allocation**.

The TMDL analysis must also consider **seasonal variation** in pollutant concentrations and include a **margin of safety** that takes into account uncertainty about the causes of the water quality problem or a water body's specific loading capacity.

Newman Lake's Inclusion on the 303(d) List

Newman Lake, located in Spokane County, 10 kilometers northeast of the City of Spokane, appears on Washington State Department of Ecology's 1996 and 1998 303(d) lists for total phosphorus (TP). (Total phosphorus is the concentration of phosphorus present in both organic and inorganic forms within the water column).

Newman Lake has, at times, experienced chronically elevated phosphorus concentrations that have lead to an accelerated growth of algae (blooms) during the summer months. These conditions have undermined the beneficial uses of the lake for activities such as fishing and swimming while importantly reducing the lake's overall biological health.

To address community concerns regarding the impaired use of Newman Lake due to poor water quality, Washington State University conducted a study of the lake in 1986. The major objective of that management plan study was to identify the principal sources of TP to the lake and to determine appropriate source control methods. Physical, chemical, and biological parameters were measured in the lake and its principal inflow sources. The Washington State Department of Ecology used the data collected during that study, and its principal findings, as the basis for including Newman Lake on the 303(d) list leading eventually to the initiation of this TMDL analysis.

Since the 1986, “Newman Lake Restoration Feasibility Study”, Washington State University (Water Research Center) has also completed, “Newman Lake Restoration Phase II” in 1998. These studies indicated that lake sediments were a major source of the phosphorus stimulating algae growth. To reduce the release of phosphorus from sediments, a whole lake alum treatment was conducted in 1989 and an aerator installed in 1992. The aerator continues to be operated.

Water quality monitoring has continued on Newman Lake by both Washington State University and lake resident volunteers. The data contained within these studies, and subsequent data collection efforts, provides the base from which this TMDL analysis was conducted.

Background

Newman Lake and its Watershed

Newman Lake is situated 10 kilometers northeast of the City of Spokane in northeast Washington. The lake has a volume of 26,146,829 cubic meters and an average depth of 5.1 meters. The maximum depth is 9 meters (30 feet) (figure 1). Its surface area is approximately 515 hectares and greater watershed 7800 hectares (figure 2). Thompson Creek, draining to the north lobe of the lake, comprises 40 percent of the watershed and has a dominant effect on the lake’s hydrology and water quality.

Forestry is the primary land use within the watershed representing approximately 78 percent of the area (table 1). Cultivated pastureland represents 6 percent of the watershed area. Residential land use, while representing less than 1 percent of the watershed area, is concentrated along the lake shoreline. There are 571 residences located along the lake shoreline with about 39 percent occupied year round. For this reason, the population within the watershed can vary considerably particularly during the summer months when use of the lake is the greatest. During the summer, the human population within the watershed is approximately 1,428.

The elevation of Newman Lake is 610 meters. Elevations within the watershed vary greatly particularly for the Thompson Creek drainage. With the exclusion of Thompson Creek, approximately 90 percent or more of the drainage area lies below 914 meters (table 2). While the majority of Thompson Creek’s drainage area is also situated below 914 meters (88 percent), 12 percent is situated above this elevation with upper elevations extending to 1676 meters. Thompson Creek’s large size, representing 40 percent of the entire watershed, and relief, result in a disproportionate effect on Newman Lake’s water quality. One of the primary factors is that during the winter months, precipitation is stored as snow in much of its drainage. The level of snow accumulation and the timing of its eventual spring runoff are major determinants on Newman Lake’s summer period TP levels.

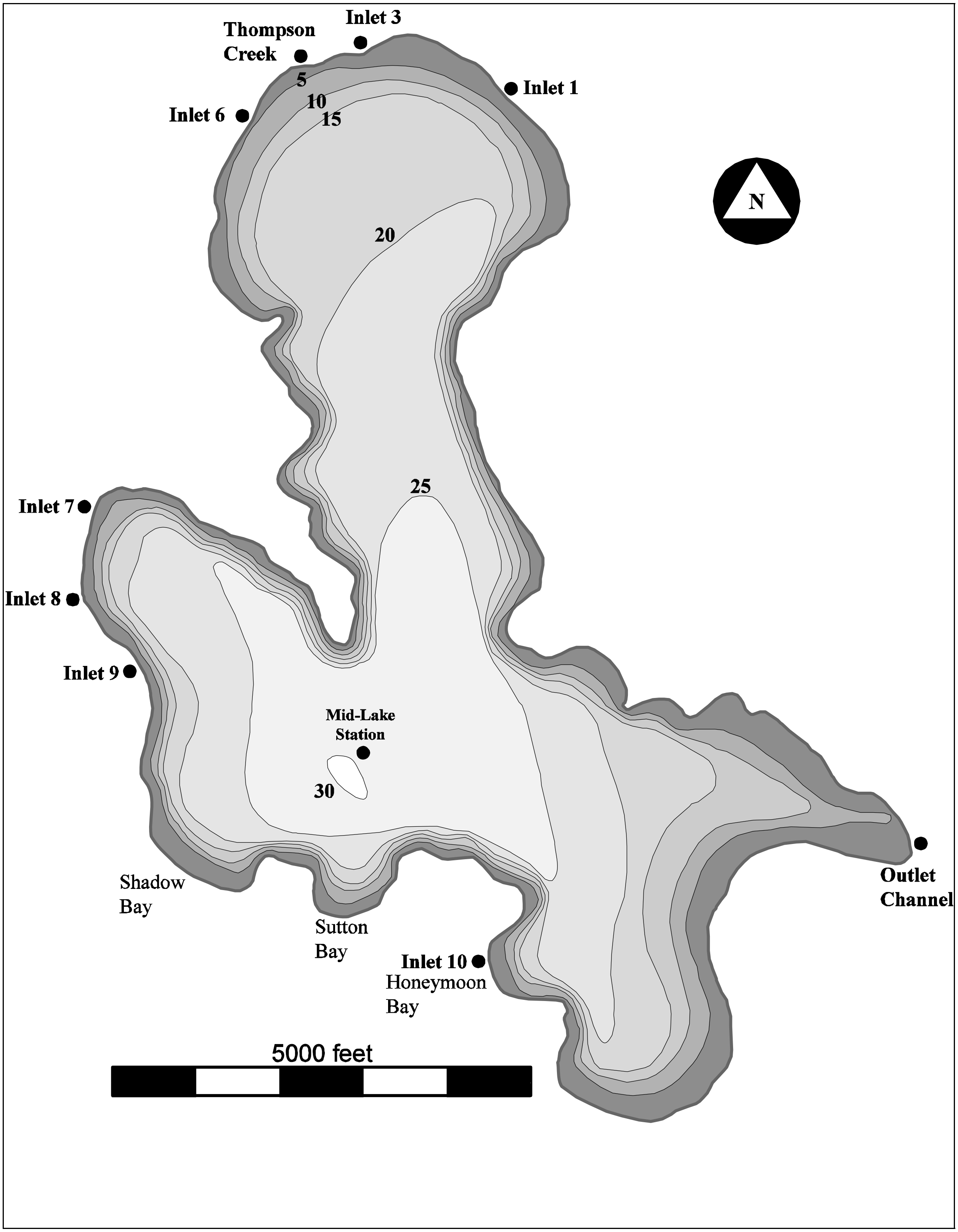

Figure 1. Newman Lake bathymetry along with monitoring locations. (Depth isopleths in units of feet.)

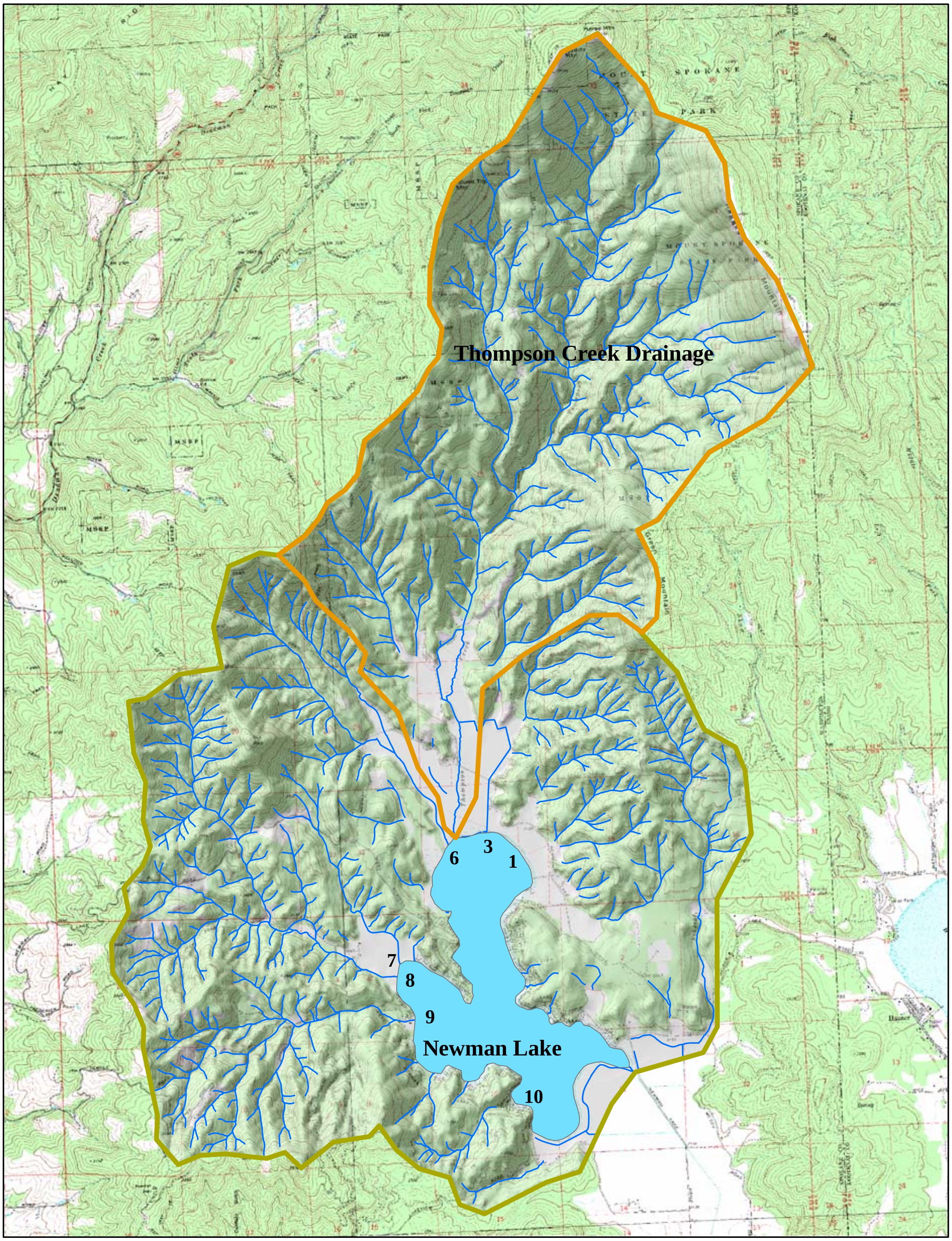

Figure 2. The Newman Lake watershed along with monitored inlet locations (numbered)

Table 1. The percent of the Newman Lake watershed represented by specific land use types.

Land Use Description (1)	Land Use Description (2)	Percent Represented (1)	Hectares (1)	Percent Represented (2)	Hectares (2)
Openwater (Newman Lake)	Open Water	6.01	467.43	6.01	467.43
Low Intensity Residential	Developed	0.13	10.11	0.18	14.16
Commercial / Industrial / Transportation	Developed	0.05	4.05		
Bare Rock / Sand / Clay	Barren	0.01	0.41	10.15	789.17
Transitional (Clearcut)	Barren	10.14	788.76		
Deciduous	Forested Upland	0.03	2.83	67.98	5285.38
Evergreen	Forested Upland	58.57	4553.68		
Mixed Tree Species	Forested Upland	9.37	728.87		
Shrubland	Shrubland	8.10	629.31	8.10	629.31
Grasslands / Herbacous	Herbaceous Upland	1.18	91.87	1.18	91.87
Pasture / Hay	Herbaceous Planted / Cultivated	3.48	270.34	6.26	492.52
Row Crops	Herbaceous Planted / Cultivated	0.17	13.36		
Small Grains	Herbaceous Planted / Cultivated	1.56	121.01		
Fallow	Herbaceous Planted / Cultivated	1.06	82.15		
Urban / Recreational Grasses	Herbaceous Planted / Cultivated	-	0.41		
Woody Wetlands	Wetland	0.12	9.31	0.14	10.52
Emergent Herbaceous Wetlands	Wetland	0.02	1.21		

Table 2. The percent of the total area within specific sub-watersheds of Lake Newman as represented by specific ranges in elevation (ft).

Elevation Range (ft)	Watershed	Thompson Creek	Inlet 6	Inlet 7	Inlet 8	Inlet 9	Inlet 3	Inlet 1	Inlet 10
2001-2500	42.3	16.7	46.6	82.6	39.8	25.0	59.6	60.5	71.4
2501-3000	29.2	23.6	38.3	16.2	52.4	50.7	35.0	39.8	29.5
3001-3500	16.5	30.3	14.7	1.2	7.9	24.4	5.1	-	0.1
3501-4000	6.5	16.1	-	-	-	-	-	-	-
4001-4500	3.8	9.4	-	-	-	-	-	-	-
4501-5000	1.6	3.8	-	-	-	-	-	-	-
5001-5500	0.1	0.2	-	-	-	-	-	-	-

Prior Water Quality Investigations and Restoration Activities

Due to concerns regarding Newman Lake's declining water quality, a diagnostic study was conducted by the Washington State University, Water Research Center in 1986 (Funk, 1988). From this work, a series of recommendations were proposed to reduce phosphorus sources and their water quality impacts. Because lake sediments were found to be a significant phosphorus source, nutrient inactivation, through the use of alum, and hypolimnetic aeration were among the recommended options. In addition, watershed management measures to control external phosphorus inputs associated with forestry, residential development, and cattle grazing, among other activities, were presented.

Since the completion of this initial feasibility study several of these recommendations have been implemented. In September 1989, a whole lake alum treatment was conducted and a Speece

Cone type hypolimnetic aerator installed in June 1992. Since 1992 the aerator has been operated each year between April and September, bracketing the period when the release of phosphorus from sediment is greatest. In 1997, the aeration system was modified with an alum injection system. Both the aerator and alum injection system are directed at reducing the release of phosphorus from sediments. Measures to control phosphorus sources within the watershed have been addressed, though less targeted, through the efforts of concerned lake residents, Spokane County Engineer's Office, Newman Lake Flood Control Zone District, the Spokane County Health Department and public and private land owners.

Applicable Criteria

Water quality standards in Washington State are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Authority to adopt rules, regulations, and standards necessary to protect the environment is the responsibility of the Department of Ecology. Under the federal Clean Water Act, the EPA Regional Administrator must approve the water quality standards adopted by the state (Section 303(c)(3)). Through adoption of water quality standards, Washington designated certain characteristic uses to be protected and the criteria necessary to protect those uses [Washington Administrative Code (WAC), Chapter 173-201A). (For additional information on Washington State's water quality standards refer to http://www.ecy.wa.gov/programs/wq/swqs/index.html.)

This TMDL addresses impairment of Newman Lake's characteristic uses and aesthetic qualities caused by the nutrient phosphorus. Elevated phosphorus levels in lake systems can result in the onset of eutrophication which is typically characterized by excessive algae growth within the upper water column. Eutrophic conditions in lakes ultimately lead to severe habitat impairment affecting the majority of aquatic organisms originally present under less adverse conditions while also leading to the loss of characteristic uses of the lake for activities such as swimming, fishing, and boating. Washington State laws relevant to the protection of water quality in Newman Lake include:

Protection of Characteristic Uses [WAC 173-201A-030(5)]

Lake Class Characteristic uses shall include, but not be limited to, the following:
1) * Water supply (domestic, industrial, agricultural).
2) Stock watering.
3) * Fish and shellfish:
    Salmonid migration, rearing, spawning, and harvesting.
    Other fish migration, rearing, spawning, and harvesting.
    Clam and mussel rearing, spawning, and harvesting.
    Crayfish rearing, spawning, and harvesting.
4) * Wildlife habitat.
5) * Recreation (primary contact recreation, sport fishing, boating, and esthetic enjoyment).
6) Commerce and navigation.

*** Characteristic uses applicable to Newman Lake**

Target Total Phosphorus Concentration

One of the primary goals of this TMDL analysis is to establish a load capacity or the maximum amount of phosphorus that can be introduced to Newman Lake from all identified sources while remaining at or below a target TP level. The target concentration provides the foundation from which the load capacity and load allocations are determined. However, there are not specific water quality criteria that apply to total phosphorus for lakes in Washington. Instead, the Department of Ecology has suggested TP target concentrations based on an eco-regional framework. Newman Lake lies within the Northern Rockies eco-region. Table 3 provides the suggested guidelines for establishing TP criteria for lakes located within the Northern Rockies eco-regions.

Based on the years monitored, median summer (June-August) TP concentrations have varied between 11.6 ug/L in 1994 to 31.8 ug/L in 1999 with an overall median of 21 ug/L. TP concentrations above 20 ug/L are indicative of a mesotrophic-eutrophic level of productivity. For these cases, a lake specific study is recommended in order to establish the target concentration.

Table 3. Washington State's recommended total phosphorus lake criteria for the Pacific Coast range, Puget Sound lowlands and Northern Rockies eco-regions.

Trophic State	Ambient TP Range (ug/L)	TP Criteria
Ultra-Oligotrophic	0 – 4	4 or less
Oligotrophic	>4 – 10	10 or less
Lower Mesotrophic	>10 – 20	20 or less
Mesotrophic – Eutrophic	>20	Lake Specific Study

Chapter 173-201A-030, Section 5(c) recommends the following be established by the lake specific study:

> Section ii – Determine appropriate total phosphorus concentrations or other nutrient criteria to protect characteristic lake uses. If the existing total phosphorus concentration is protective of characteristics uses, then set criteria at the existing total phosphorus concentration. If the existing total phosphorus concentration is not protective of the existing characteristic lake uses, then set criteria at a protective concentration. Proposals to adopt appropriate total phosphorus criteria to protect characteristic uses must be developed by considering technical information and stakeholder input as part of a public involvement process equivalent to the Administrative Procedure Act (Chapter 34.05 RCW).
>
> Section iii – Determine if the proposed total phosphorus criteria necessary to protect characteristic uses is achievable. If the recommended criterion is not achievable and if the characteristic use the criterion is intended to protect is not an existing use, then a higher criterion may be proposed in conformance with 40 CFR part 131.10.

This TMDL analysis uses the information contained within the "Newman Lake Restoration Feasibility Study" (Funk, 1988) and the "Newman Lake Restoration Phase II" study (Funk, 1998) as the basis for the lake specific study. The results of those investigations indicated that a shift in the trophic status from mesotrophic/eutrophic to mesotrophic will result in the achievement of the lake's beneficial uses. A lower in-lake total phosphorus concentration, the result of source control, will further shift the environmental conditions which favor excessive algae growth, the major factor sited as impairing characteristic uses of the lake.

A target TP concentration establishes a maximum level that should be observed, on average, within the epilimnion (0 to 3 meter depths) during the summer period (June through August), while remaining protective of the lake's characteristic uses. The reason for a summer period target is that summer is when Newman Lake receives the greatest recreational use coincident with when algae growth is at its peak. The target concentration applies to the epilimnion portion of the water column because this is the section of the lake where both recreational use and algae growth are concentrated.

To achieve this trophic shift, a target summer period (June through August) total phosphorus concentration for the epilimnion of Newman Lake is set at 20 micrograms per liter (ug/L).

Epilimnion Target Summer Period Total Phosphorus Concentration

- 20 micrograms per liter (ug/L)

In lake systems, among the most evident effects to water quality from the elevated loading of phosphorus is increased growth of algae during the summer months. Excessive algae growth reduces water clarity, results in chronic increased oxygen demand in the bottom sediments severely impacting coldwater aquatic habitat and can, depending on the dominant algae present, pose a human health risk. Historically, Newman Lake has experienced toxic blue-green algae blooms in 1983 and again in 1985. The mechanism triggering toxic blue-green algae growth is not fully understood through an environment with an elevated supply of phosphorus tends to favor the dominance of blue-green algae in relation to other types of phytoplankton.

A gauge on significant water quality improvements and the achievement of beneficial uses can be indicated by the Trophic State Index (TSI) (Carlson, 1977). The TSI uses the level of three parameters including total phosphorus, Secchi depth, a measure of water clarity, and chlorophyll(a), an indication of algae growth levels, to evaluate the trophic state, or productivity, of a lake. Ranges in the values for these parameters, (typically applying for the summer months) as they relate to the trophic state, are provided in table 4.

Table 4. The range in TSI parameters as they relate to lake trophic status.

Trophic State	Secchi Depth (m)	Chl(a) (ug/L)	TP (ug/L)	TSI
Oligotrophic	> 4	< 3	< 14	< 40
Mesotrophic	2 – 4	3 – 9	14 – 25	40 – 50
Eutrophic	< 2	> 9	> 25	> 50

Figures 3 and 4 provide box plots depicting the relationship between total phosphorus, chlorophyll (a), and Secchi depth observed in Newman Lake's epilimnion based on study data along with additional data collected by Spokane County and Washington State University between 1986 and 1992.

In interpreting the box plots, the top and bottom of the vertical lines (blue open squares) represent the 90th percentile and the 10th percentile, respectively. The top and bottom of the box depict the 75th and 25th percentile of the data, respectively. The median level is represented by the solid (red) square. As a comparison, the open circles in these figures are the results of similar relationships derived from a large dataset derived from North American lakes (Dillion, 1974)

Based on these figures, with the achievement of the target TP concentration of 20 ug/L, a chlorophyll (a) concentration of between approximately 7 and 5 ug/L can be expected (represented by the 75th and 25th percentiles of the >10-20 ug/L range of TP) resulting in a Secchi depth of approximately 4 meters. The trophic state index, based on these parameter values, will bring Newman Lake from 48, indicative of an eutrophic/mesotrophic state, to 44, indicative of a lower mesotrophic state.

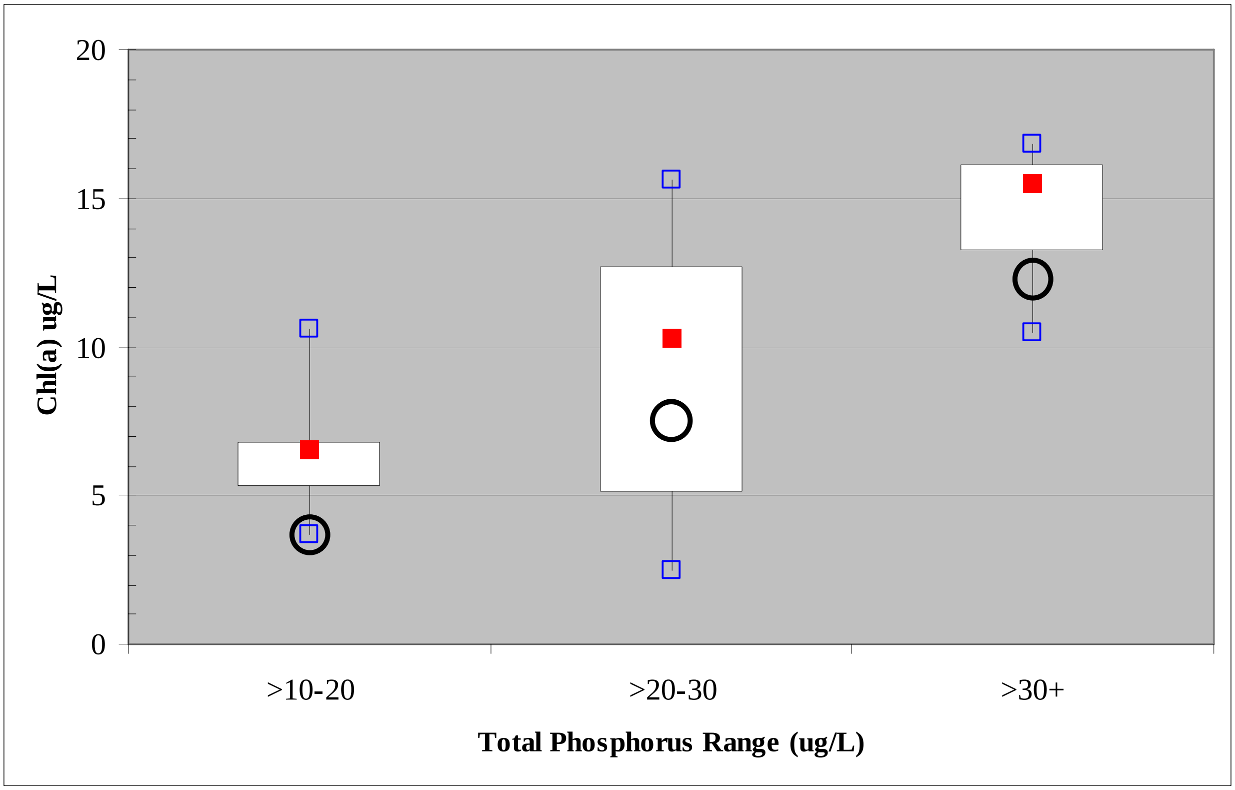

Figure 3. The relationship between TP and chlorophyll (a) concentrations. (Circles are from Dillon, 1974).

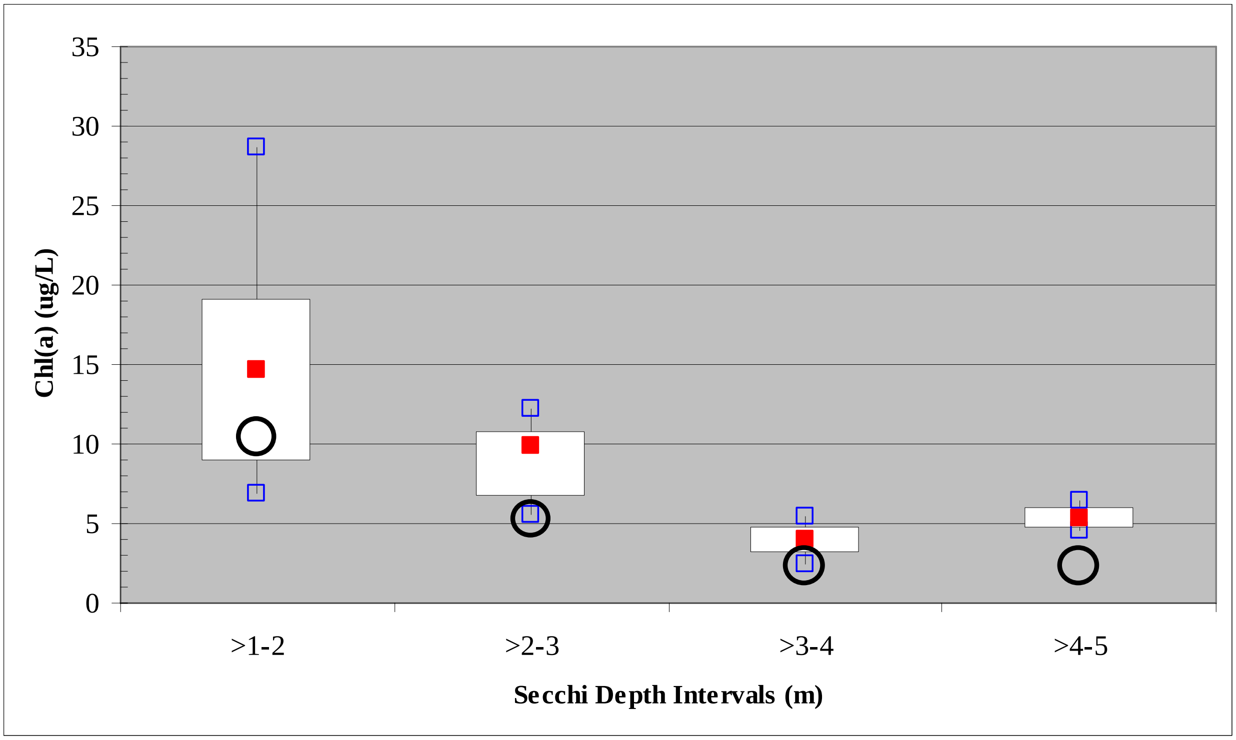

Figure 4. The relationship between Secchi depth and chlorophyll (a) concentrations observed in Newman Lake. (Circles are from Dillon & Rigler, 1974).

Water Quality and Resource Impairments

Lakes can be characterized by their level of biological productivity, or trophic state. A lake's natural level of productivity is determined by factors such as its geologic setting, watershed size and relief, bathymetric characteristics, climate, and the quantity and quality of the water entering and leaving the lake. Increases in a lake's productivity over time, known as eutrophication, is a natural process though for many lakes such as Newman Lake this process has been accelerated by human-related activities. Surface and groundwater inflow associated with non-point pollution sources such as residential and commercial development and maintenance are a few of the pathways present in the Newman Lake drainage area that contribute phosphorus either directly to the lake or to inflowing surface waters ultimately resulting in an increase in the lake's productivity.

Stratification, or the separation of the water column based on differences in temperature, is a process having a significant effect on the supply and distribution of total phosphorus in Newman Lake. For this reason, within this section of the report, an overview of stratification will be presented followed by a discussion of its influence on total phosphorus dynamics.

The aerator is another influence on Newman Lakes phosphorus dynamics. Originally installed in 1992, the aerator has been operated each year since between the months of April and September. The intended purpose of aerator is to limit the release of phosphorus from sediments by maintaining higher dissolved oxygen concentrations at the bottom of the lake. Concentrations of dissolved oxygen had been observed at negligible levels during the summer months resulting in the release of phosphorus from sediments. Because of this influence, the effect that the aerator has on the lake's water quality, in particular dissolved oxygen, temperature, and TP will be discussed.

Stratification - Patterns to Phosphorus Enrichment and Circulation

During the spring of each year, increased solar radiation levels selectively heat the upper water column of Newman Lake. Heat is primarily absorbed within the upper 2-meters of the water column with greatly reduced heat transfer to the deeper portions of the lake. The density of water (its weight per volume) is a function of its temperature with density decreasing with increases in temperature. (Warmer water is lighter than colder water up to the point of freezing.) For this reason, from May to September, a warmer less dense layer of the water column resides over a colder denser layer. This water column separation is known as stratification. The upper warmer and well mixed layer is known as the epilimnion and the lower colder layer is known as the hypolimnion. This temperature gradient has a significant effect on the distribution of TP within the water column.

Within the epilimnion, dissolved oxygen concentrations are maintained through diffusion from surface air and primary production (plant and algae). In contrast, the hypolimnion is isolated from the surface, without a re-aeration pathway. Microbial decomposition of organic matter present within the sediments rapidly uses what available dissolved oxygen was present prior to the onset of stratification. Decomposition continues through at a lower rate without oxygen under anaerobic conditions. Because it is not in circulation with the surface, there is no mechanism to replenish dissolved oxygen levels. While stratification is a natural process, the rate in the decline of hypolimnetic dissolved oxygen is an indication of the level of organic enrichment of the sediments and therefore, a measure of eutrophication.

Once dissolved oxygen levels decline below approximately 2 milligrams per liter (mg/L) phosphorus, bound to sediment at higher dissolved oxygen levels, is released into the water column in a dissolved state. The sediment release of phosphorus is a process known as internal recycling. If a lake is strongly stratified and deep, phosphorus released from bottom sediments remains primarily within the hypolimnion. Lakes vulnerable to eutrophication, a condition characterized by elevated phosphorus levels and associated algae concentrations, are those with a shallow mean depth with higher organic content to the bottom sediments. These are the conditions present within Newman Lake. In these lakes there is a close proximity between high phosphorus concentrations in the hypolimnion (supply) and where algae grow (demand) within the euphotic zone. The mechanisms that move phosphorus from the hypolimnion to the epilimnion can occur through diffusion (high concentration to low concentration) and through water column mixing. Mixing can occur through a rapid loss of heat within the epilimnion associated with a low pressure weather system, high winds, or high inflow levels.

Within Newman Lake, the maximum release of dissolved phosphorus from anaerobic sediments occurs from mid-July until lake turnover in September. By mid-August, stratification begins to erode with decreasing solar radiation levels and surface cooling. When this occurs, the upper water column begins to mix to greater and greater depths as it gradually cools. This process is complete by early-September with complete lake turnover resulting in uniform temperatures throughout the water column. As the upper water column begins to cool and mix to greater depths it entrains water containing higher phosphorus levels situated within the lower water column. For this reason, phosphorus concentrations in the upper water column increase rapidly in September and October in comparison to levels observed in during mid-summer.

Effect of Aerator on Lake Stratification

Stratification and the internal recycling of phosphorus are processes that occur each year in Newman Lake and the hypolimnetic aerator and alum injection systems are both directed at reducing the conditions that lead to internal recycling. While the aerator is directed at increasing dissolved oxygen levels in the hypolimnion it also appears to be affecting lower water column temperatures.

Figures 5 and 6 display the median observed water temperature, by depth, prior to and following the installation of the aerator. The comparison of pre and post-aerator temperature profiles during the stratification period indicate that temperatures are similar in magnitude and heating pattern during May. However, deviations in the profiles occur during the summer period, June through August. During this period, water temperatures observed within the upper four meters of the water column are similar while below 6 meters depth (within the hypolimnion) the profiles diverge.

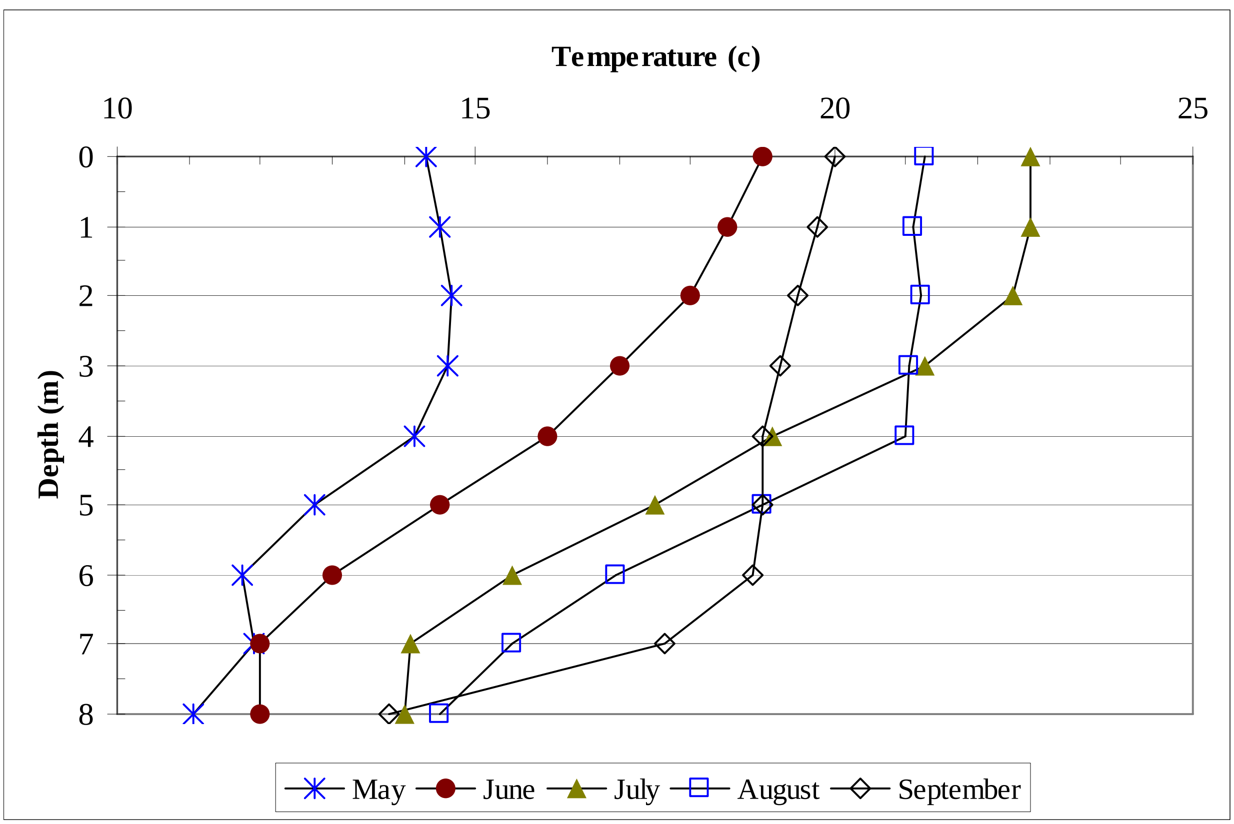

Figure 5. Median monthly water temperatures, by depth, prior to the installation of the aerator.

Prior to the aerators installation, June, July and August median temperatures, from 6 meters to the bottom, were 12.0 °C, 14.1°C, and 15.5°C, respectively. Now, with the aerator in place, median temperatures have increased. June, July and August median hypolimnion temperatures are 15.4 °C, 17.9 °C, and 21.0 °C, respectively. This results in temperature increases of 3.3 °C, 3.7 °C, and 5.5 °C, respectively. This increase in hypolimnion temperatures decreases the strength of stratification as indicated by the difference between epilimnion and hypolimnion temperatures. One of the consequences of the reduced level of stratification is that complete lake turnover, which typically occurred in September, now occurs in August. This is the reason for the 5.5 °C difference between pre and post-aerator August temperature profiles.

An explanation for the increase in hypolimnion temperatures is that the aerator may be facilitating lower water column mixing and, in the process, passing heat from the epilimnion to the hypolimnion. The comparison of pre and post-aerator dissolved oxygen profiles provide a further indication of lower water column movement.

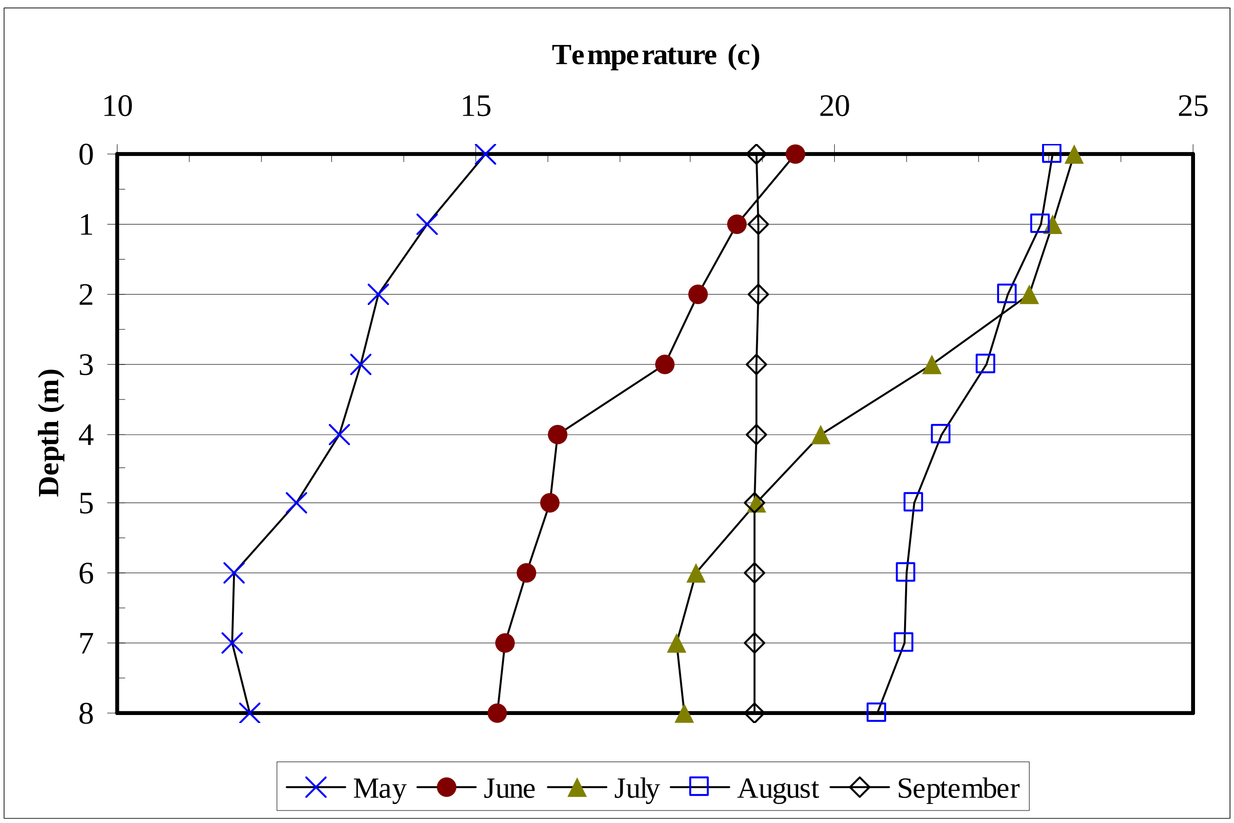

Figure 6. Median monthly water temperatures, by depth, following the installation of the aerator.

The pre and post-aerator dissolved oxygen profiles for May and June are similar from the surface to approximately 6 meters depth (figures 7 and 8). Below 6 meters post-aerator dissolved oxygen levels are higher by about 2 mg/L. The dissolved oxygen profiles deviate during July and August. For July, similar dissolved oxygen levels are present from the surface to 3 meters at 8 mg/L and from 7 meters to the bottom, where negligible dissolved oxygen concentrations are typically observed. The real change is through the middle water column where post-aerator dissolved oxygen concentrations have declined in comparison to pre-aerator levels.

During July, at depths 4, 5, and 6 meters, median dissolved oxygen levels have declined by 2.8 mg/L, 4.4 mg/L, and 3.3 mg/L, respectively. A similar pattern is present for August dissolved oxygen profiles. During August, similar dissolved oxygen profiles are present from the surface to 2 meters and 6 meters to the bottom. Deviations occur through the middle water column at 4 and 5 meter depths. Pre aerator dissolved oxygen levels were 2.2 mg/L and 2.9 mg/L greater in comparison to post aerator levels for these depths. Evident in comparing the profiles in figures 7 and 8 is that prior to the installation of the aerator, dissolved oxygen profiles were vertical (similar dissolved oxygen concentrations) from the surface to approximately 4 meters. Below 4 meters, concentrations declined rapidly. Now, vertical profiles extent to just 2 meters with a more gradual decline to dissolved oxygen concentrations through the metalimnion.

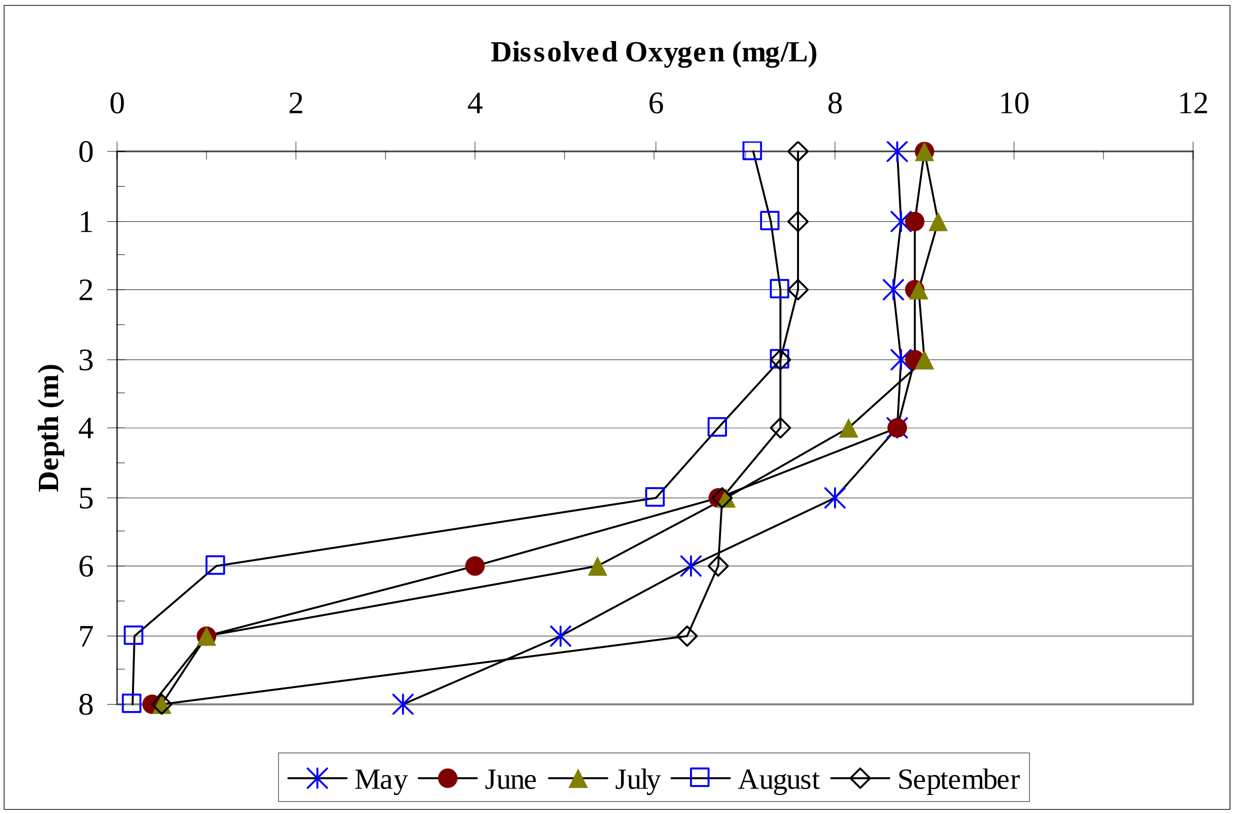

Figure 7. Monthly median dissolved oxygen concentrations (mg/L) by depth prior to the installation of the aerator.

Together, the increase in hypolimnion temperatures and decrease in middle water column dissolved oxygen concentrations indicate that the aerator is likely facilitating lower water column mixing. Mixing has facilitated the passage of heat from the upper water column to the lower water column leading to increased hypolimnion temperatures. Sediment oxygen demand continues to be high with the result that mixing has reduced dissolved oxygen concentrations within the middle water column and hypolimnion concentrations, during peak stratification (July-August), remain low. However, mixing appears to be limited to the lower water column because pre and post-aerator dissolved oxygen and temperature levels within the upper 2 to 3 meters remain similar.

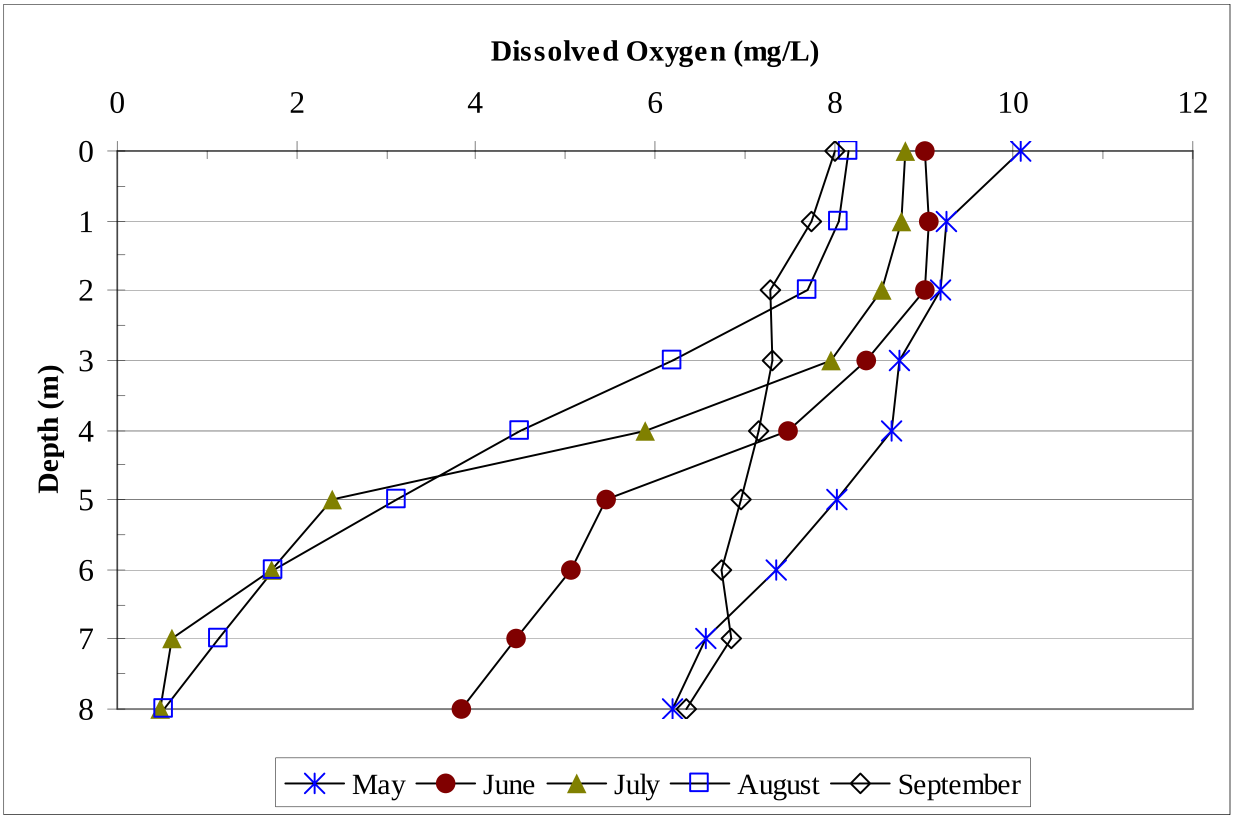

Figure 8. Monthly median dissolved oxygen concentrations (mg/L) by depth following the installation of the aerator.

Seasonal Variation

Lake Total Phosphorus Concentrations – Seasonal and Annual Variation

June through August is a critical period for evaluating trophic conditions of lakes in this region. This is a period when environmental conditions supporting primary productivity are at their peak. The level of primary productivity, based on the amount and type of algae present, are both indicators of the availability of nutrients in particular, phosphorus. Depending on its level of availability phosphorus can stimulate the rapid growth of free floating or planktonic algae (phytoplankton) leading to conditions known as blooms. Lakes with chronically elevated levels of phosphorus tend to have a reduced diversity of phytoplankton dominated by cyanobacteria or blue-green algae. Although not common, under certain conditions, and based on the species present, blue-green algae can be toxic if ingested. Historically, Newman Lake has had two toxic blue-green algae blooms (1983 and 1985) (Funk, 1998).

Monthly Variation

The TP data used in this analysis was collected at the mid-lake station (refer to figure 1). Samples were collected at 0.5 (surface), 4, and 8 meter depths.

Since 1992, following the introduction of the aerator to Newman Lake, total phosphorus concentrations at the surface (0.5 meters depth) have averaged around 21 ug/L during the June through August period (table 5). Based on TP concentrations observed during April through October, (when the majority of the samples have been collected historically), the summer months have among the lowest concentrations. The variation in monthly concentrations range from October at approximately 35 ug/L to 20 ug/L during July and August. The higher concentrations observed in October are the result of full water column mixing following lake stratification. As the upper water column begins to cool by mid-August it begins to mix to a greater depth and in the process entrains water containing higher phosphorus levels situated within the lower water column. This is the reason why phosphorus concentrations increase in September and October in comparison to levels observed in August.

TP concentrations observed at 8-meters (median of 41 ug/L) during the summer are approximately twice the level observed at the lake surface. This is indicative of the release of TP from the sediments known as internal recycling. The current in-lake management measure of hypolimnetic aeration is directed at limiting the release of phosphorus from sediments by maintaining higher dissolved oxygen concentrations within the hypolimnion. That during the summer period the upper water column has its lowest TP concentrations while the lower water column has among its highest indicates that the release of phosphorus from sediments continues however, this source of phosphorus is not, on average, migrating to the surface.

Table 5. Monthly median total phosphorus concentrations (ug/L) by month along with the whole lake weighted average concentration, 1993 to 2004.

Month	**Depth (m)**			**Whole Lake Weighted Average**	**Number of Observations (n)**
	0.5	**4.0**	**8.0**		
January	18.7	27.8	162.0	44.4	1
February	-	-	-	-	-
March	14.0	33.0	30.0	25.4	6
April	27.8	30.9	30.0	29.3	12
May	23.9	29.0	35.0	27.8	16
June	22.0	38.0	45.0	32.9	9
July	20.0	24.7	33.0	24.0	9
August	19.7	30.0	30.9	26.1	11
September	25.0	28.0	30.5	27.0	12
October	34.5	33.0	37.4	33.9	12
November	56.3	54.3	52.8	54.2	2
December	-	-	-	-	-

Prior to 1992, TP concentrations within the upper water column were similar to those observed following the installation of the aerator (table 6, figure 9) with median summer concentrations observed at 18 ug/L. Again, TP concentrations observed during the summer were among the lowest observed during the year (table 6). Median hypolimnetic concentrations were, however, higher with overall median levels of 58 ug/L.

Table 6. Monthly median total phosphorus concentrations (ug/L) by month along with the whole lake weighted average concentration, 1986 to 1992.

Month	**Depth (m)**			**Whole Lake Weighted Average**	**Number of Observations (n)**
	0.5	**4.0**	**8.0**		
January	39.0	77.0	92.0	64.8	3
February	-	-	-	-	-
March	34.5	29.5	32.5	31.5	2
April	22.0	26.0	34.5	25.6	4
May	20.0	24.5	27.0	23.0	5
June	16.0	22.0	45.0	23.1	5
July	18.0	20.0	49.0	23.4	4
August	20.5	24.0	204.0	49.5	6
September	25.5	25.5	57.0	30.0	6
October	33.0	33.5	37.0	33.5	2
November	18.0	28.5	28.5	24.4	2
December	19.5	19.5	34.0	21.5	2

The real difference made by the aerator is evident in the median TP concentrations for the month of August. The pre and post aerator TP concentrations at the 8.0 meter depth is 204 ug/L and 31 ug/L, respectively.

Figure 9 displays box plots of TP concentrations observed during the June through August period prior to and following the installation of the aerator. Median summer TP concentrations observed within the epilimnion are similar for the pre and post-aerator periods (figure 9). This indicates that the aerator has had only a minor influence on epilimnion TP concentrations. It also indicates that only under unusual conditions does the hypolimnion and epilimnion mix during the summer. Rapid warming of the snow pack (rain-on-snow events) or unusually high precipitation events and associated runoff or low pressure systems bringing cold air and high winds are forces that have historically resulted in water column mixing. However, the occurrence of these type of events are unusual during the stratification period.

At the surface (0.5 m), median TP concentrations of the pre and post aerator period are observed at a similar levels at 18 ug/L and 20 ug/L, respectively. Concentrations at 4 meters are slightly higher for the post aerator period at 27 ug/L in comparison to the previous level of 21 ug/L. Post aerator concentrations observed at 0.5 and 4 meters also have greater variability though this may be due to the greater range in TP loading following 1992 (to be discussed later in this report). Within the hypolimnion, concentrations have declined from a median of 58 ug/L to 40 ug/L. Prior to 1992, the TP concentrations observed at 4 meters were significantly lower than those observed in the hypolimnion. Now, due to lower hypolimnion (8 meter) concentrations and greater variability at 4 meters, TP concentrations are not significantly different. Evaluated as a whole lake weighted average, based on summer period median TP concentrations, the pre and post-aerator periods are similar at 25 ug/L and 26 ug/L, respectively.

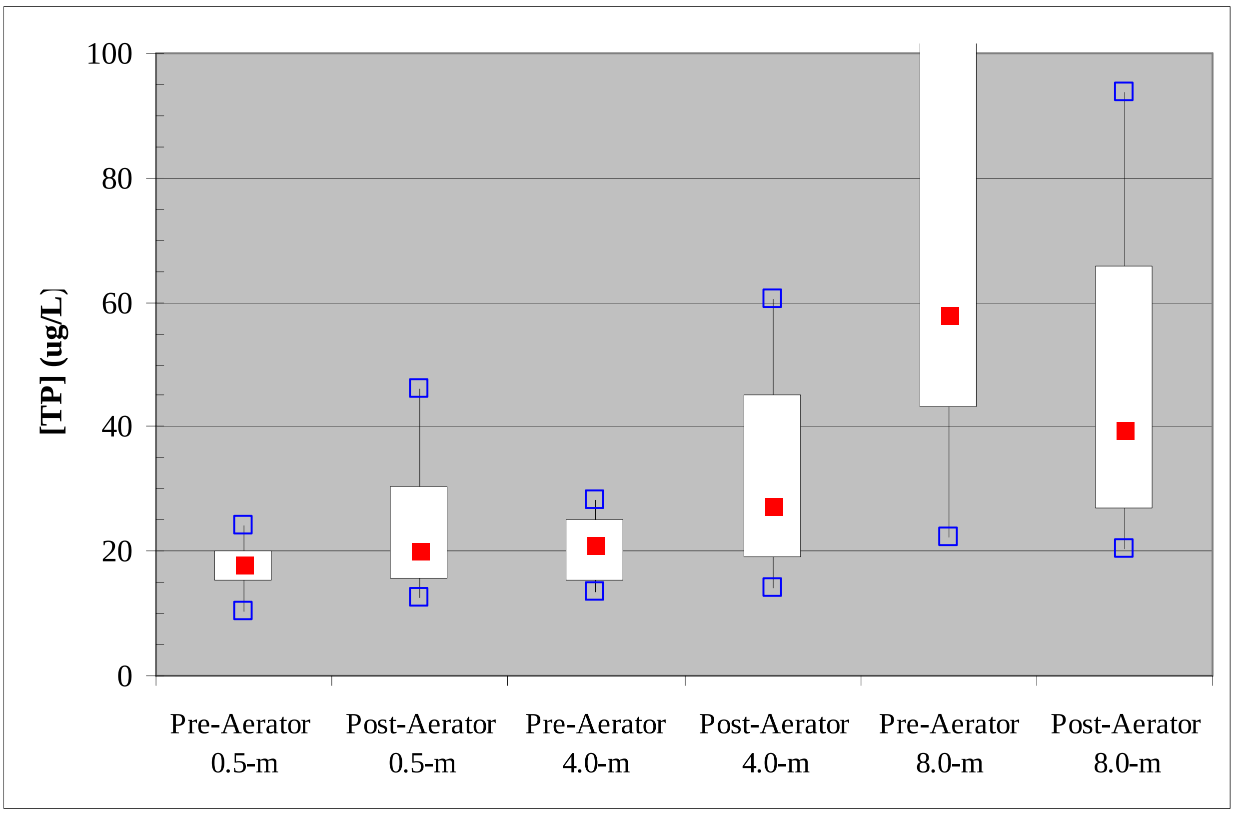

Figure 9. Box plots comparing pre and post aerator TP concentrations observed at 0.5, 4.0, and 8.0 meters during the summer period, June through August.

Annual Variation

Summer median TP concentrations observed at the surface (0.5 meter depth) of Newman Lake varied between 12 ug/L in 1994 to 32 ug/L in 1999 (figure 10). The overall median concentration for the summer periods monitored is approximately 20 ug/L. The annual variation in summer median TP concentrations observed for 4 meters followed relatively closely the variation observed at the surface; lows occurring in 2003 and 1994 at approximately 16 ug/L with the high observed in 1998 at 51 ug/L. While for the majority of the years, the median TP concentrations observed at 0.5 and 4 meters were relatively similar, larger deviations occurred in 1998, 1999 and 2002. As it will be discussed, these were years when higher inflow and, therefore, external phosphorus loading occurred. During the summer period this inflow is directed to the upper water column resulting in increased phosphorus concentrations. For the years TP concentrations were measured in Newman Lake, the greatest level of inflow during the summer period occurred in 1998 and 1999 with the lowest levels observed in 1992 and 1994. This is the reason why concentrations increase within the upper and middle of the water column while the lower water column is relatively unaffected. The exception is 2002 when lake de-stratification occurred by mid-August bringing phosphorus-rich water to the upper water column.

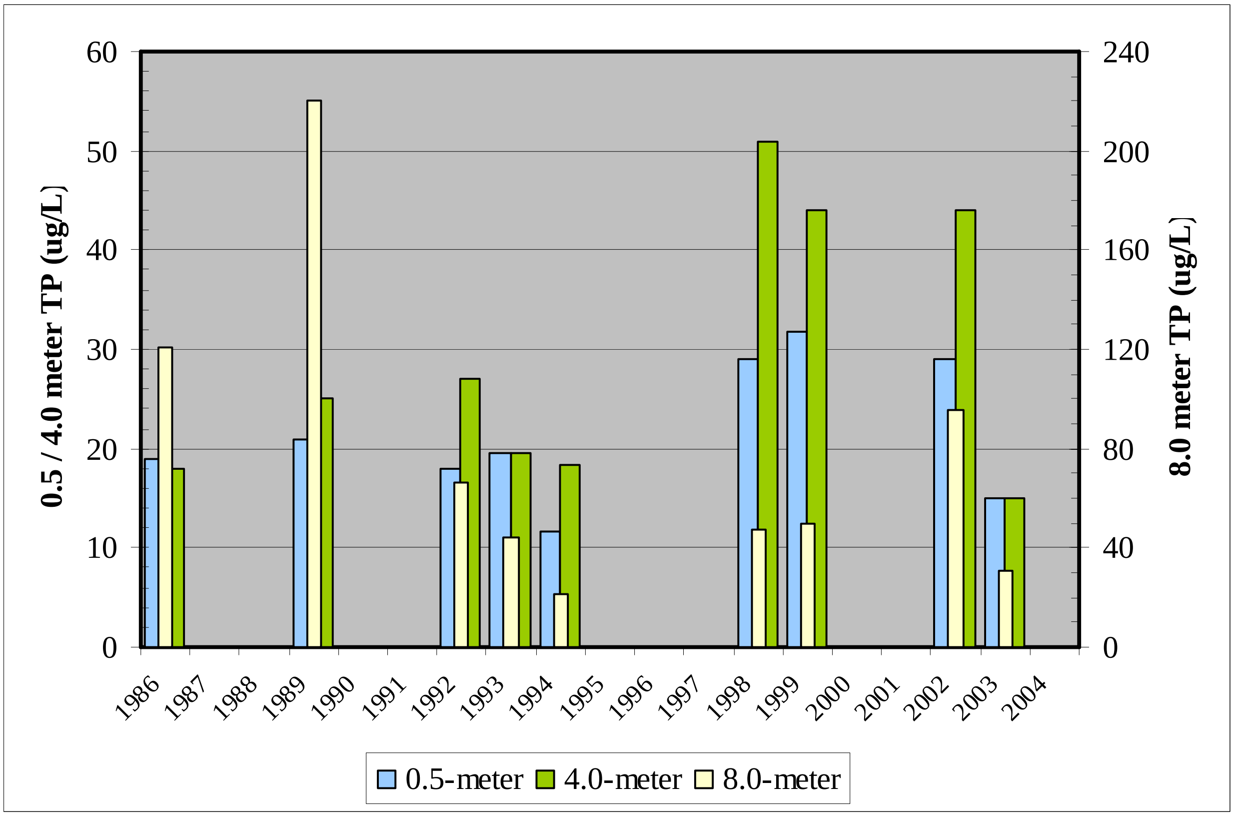

Figure 10. Median summer period TP concentrations (ug/L) observed at the mid-lake monitoring station at 0.5, 4, and 8 meter depths between 1986 and 2004.

Within the lower water column, decreased TP concentrations have occurred following the alum treatment in 1989 and the installation of the aerator in 1992. Prior summer median TP concentrations were observed at 121 ug/L and 220 ug/L in 1986 and 1989, respectively. Since 1992, concentrations range from 95 ug/L in 2002 to 22 ug/L in 1994 (figure 10).

Technical Analysis

Among the major objectives of this analysis was to identify and quantify the major TP sources to Newman Lake. Through this process, a phosphorus budget was constructed examining the various pathways phosphorus is gained and lost from the lake over time. The budget allows an examination of what pathways contribute a disproportionately high level of phosphorus to the lake. The budget is also provides critical information for establishing the load capacity and load allocations.

The first analysis step was to determine the level of inflow to the lake over the analysis period. Sources of inflow include precipitation falling directly on the lake, surface water inflow, and inflow associated with groundwater. Once inflow levels were defined, the TP concentrations associated with those inflows were examined. With an understanding of flow and concentration, a load, or the mass of TP over time, was calculated. The TP load is determined by multiplying the concentration of phosphorus observed in the water by the level of flow measured at the time the water sample was collected. In this study, the load is in units of kilograms (kg) of total phosphorus (TP) over time. The calculation of loads is fundamental to the TMDL analysis.

TP sources to Newman Lake can be divided into two categories: those internal to the lake, primarily through the release of TP from sediments under anaerobic conditions and those external to the lake such as TP present within surface water inflow. The external sources considered as part of this analysis include: precipitation, surface water inflow, and on-site wastewater systems. Based on an analysis of land use within the Newman Lake watershed, the primary influence on groundwater TP levels is from residential on-site systems. For this reason, the influence of groundwater inflow on lake TP concentrations focused solely on the TP load associated with on-site systems. The external TP loads were calculated on a monthly basis from 1985 through 2004 and served as input to a TP model. The model was used to estimate the internal TP recycling component of the nutrient budget.

Within this section of the report, the calculation of inflow levels associated with external sources will be discussed along with the determination of TP concentrations associated with those inflows. This will be followed by the presentation and application of the lake model. The model was used to better understand the link between variations in internal and external TP loads and lake water column concentrations. The model also allowed the examination of how reductions in TP from specific sources effect in-lake TP concentrations. This, in turn allowed the determination of the load capacity and source allocations.

External TP Sources and Loads

Thompson Creek

Forty-nine measurements of flow have collected in Thompson Creek over a 30-year period through a range of flow conditions. In order to provide a fuller picture of the variation in flow observed at Thompson Creek, these flow measurements were compared with daily average flow levels recorded at a near by United States Geologic Survey flow gauging station (12431000) located on the Little Spokane River at Dartford (figure 11). From this relationship, the daily average flow for Thompson Creek was estimated for the analysis period, 1985 through 2004.

With an understanding of the variation in Thompson Creek flow, the relationship between it and TP concentrations was examined. This relationship, if present, would then provide an approach for calculating the daily average TP load.

The relationship between TP and flow for Thompson Creek is presented in figure 12. A least squares (best fit) line has been drawn through the data. The flat least squares line indicates that there is no significant relationship between the level of flow and observed TP concentrations. Typically, in most surface waters, the variation in TP concentration is closely related to the level of total suspended solids. Phosphorus is adsorbed to sediment particles so when flow levels are higher, and sediment is mobilized, TP concentrations are also higher. In fact, the majority of the annual TP load is commonly attributed to just a few large storm-events that both deliver and transport high suspended solids levels within surface waters. For this reason, the frequency and timing of sample collection, particularly during storm-events, is important in examining TP loads. However, for Thompson Creek there does not appear to be a relationship between flow (and associated suspended sediment levels) and TP. An explanation as to why this relationship does not occur is that typically the highest flow levels in Thompson Creek are associated with snow melt during the spring. Flow associated with snow melt does not generate as high of in-stream sediment levels in comparison to more erosive run off processes such as those associated with heavy rain storms.

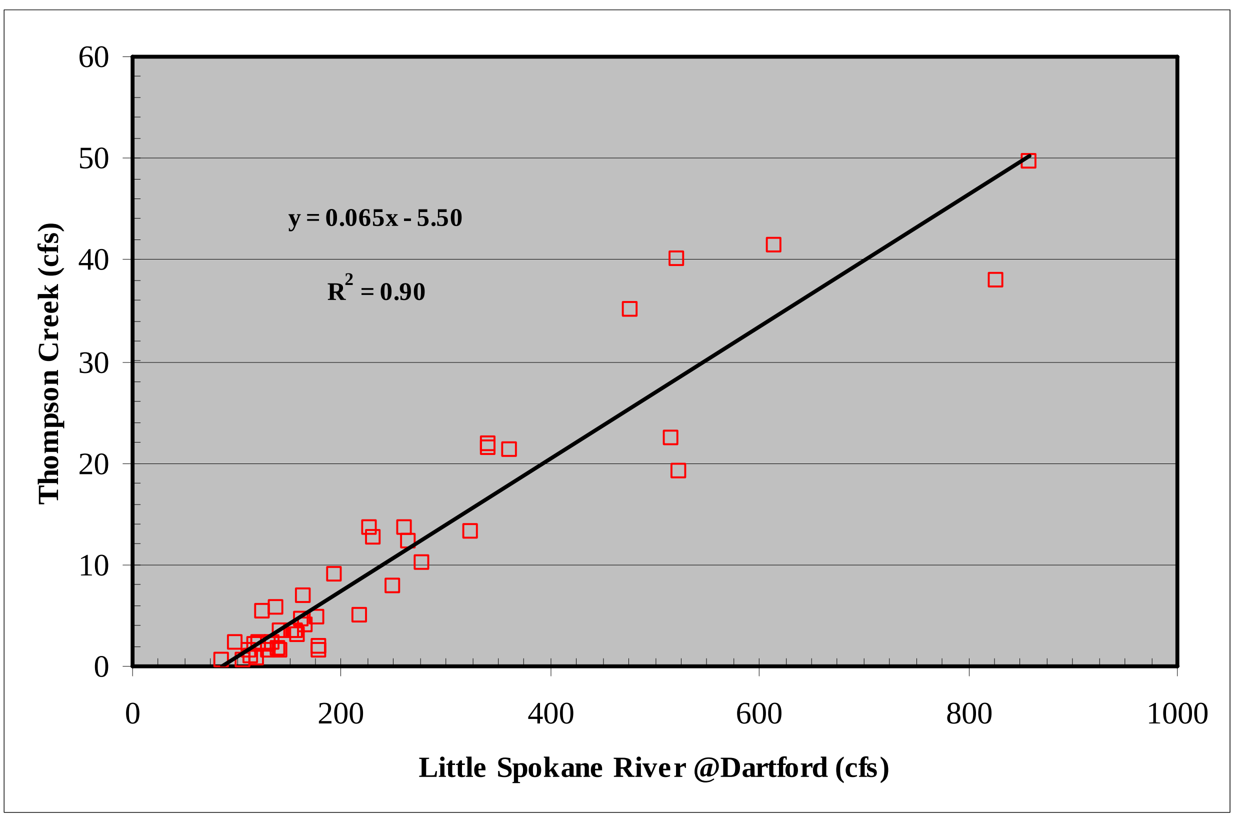

Figure 11. The relationship between the daily average flow recorded at the Little Spokane River and that measured at Thompson Creek.

Because TP concentrations remain relatively constant despite varying flow levels, an overall median TP concentration of 47 ug/L was used to calculate loads. So in calculating daily loads, the daily average flow level was multiplied by 47 ug/L and converted into units of kilograms per day.

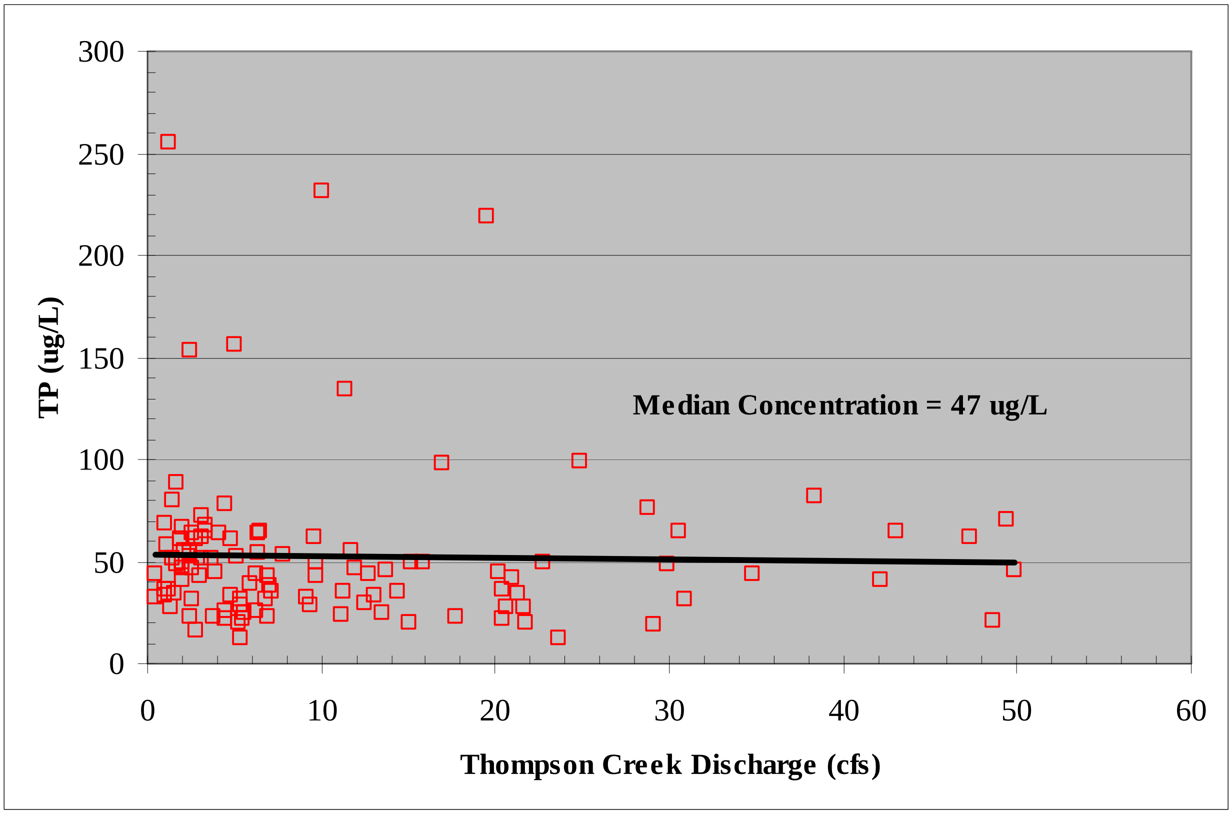

Figure 12. The relationship between discharge (cubic feet per second, cfs) and TP concentrations (ug/L).

Watershed Drainage

In addition to Thompson Creek, TP concentrations and flow levels have been measured at seven other surface water inflow points to Newman Lake. Figure 1 displays the monitoring locations of each of these inlets. Monthly flow estimates were determined for each of these drainages from July 1989 through December 1990 (Funk, 1998) providing the best available information for these locations.

Based on monthly 1990 measurements, flows measured at inlet sites 1, 7-9 were summed to determine monthly totals. The monthly flows were divided by the total drainage area represented (7.0 mi^2) to calculate a monthly water yield (cfs/mi^2-mo). The yields were then used to estimate the total inflow, on a monthly basis, throughout Newman Lake's watershed exclusive of Thompson Creek.

A power regression was determined between the 1990 monthly average flow levels observed in Thompson Creek and those calculated for the greater watershed. The relationship resulted in the equation $y=0.18x^{1.36}$, n=12, $r^2=0.85$). Y equals the average monthly inflow of the watershed (excluding Thompson Creek) based on the average monthly Thompson Creek flow. (Units are in cubic feet per second.) This relationship was then applied to calculate average monthly inflow levels for the watershed, based on average monthly Thompson Creek flow levels, for the analysis period 1985 to 2004.
Figure 13 displays box plots of the TP concentrations observed at each of the inflow monitoring stations. Box plots indicate the variation in concentrations. In interpreting box plots, the upper and lower edges of the box represent the 75th and 25th percentile of the TP concentrations. The solid square within the box is the median concentration. The median concentration indicates that of the concentrations measured at each site, 50 percent of the samples are greater than and 50 percent less than this value. The 75th percentile concentration indicates that 75 percent of the measured samples are less than this concentration.

Median concentrations varied between 36 ug/L at inlet 1, to 103 ug/L at inlet 10. The median concentration of Thompson Creek is 47 ug/L. Exclusive of Thompson Creek, the median TP concentration among the inlet stations is 74 ug/L. In comparison, the median TP concentration observed at inlet 1 was approximately half, a level more representative of less impacted conditions. In contrast, the higher TP level observed at inlet 10 is likely the influence of residential development located in proximity to Honeymoon Bay.

To calculate the TP monthly loads associated with the watershed inflow, an overall median TP concentration of 74 ug/L was applied. The monthly totals were summed to determine annual loads from 1985 to 2004.

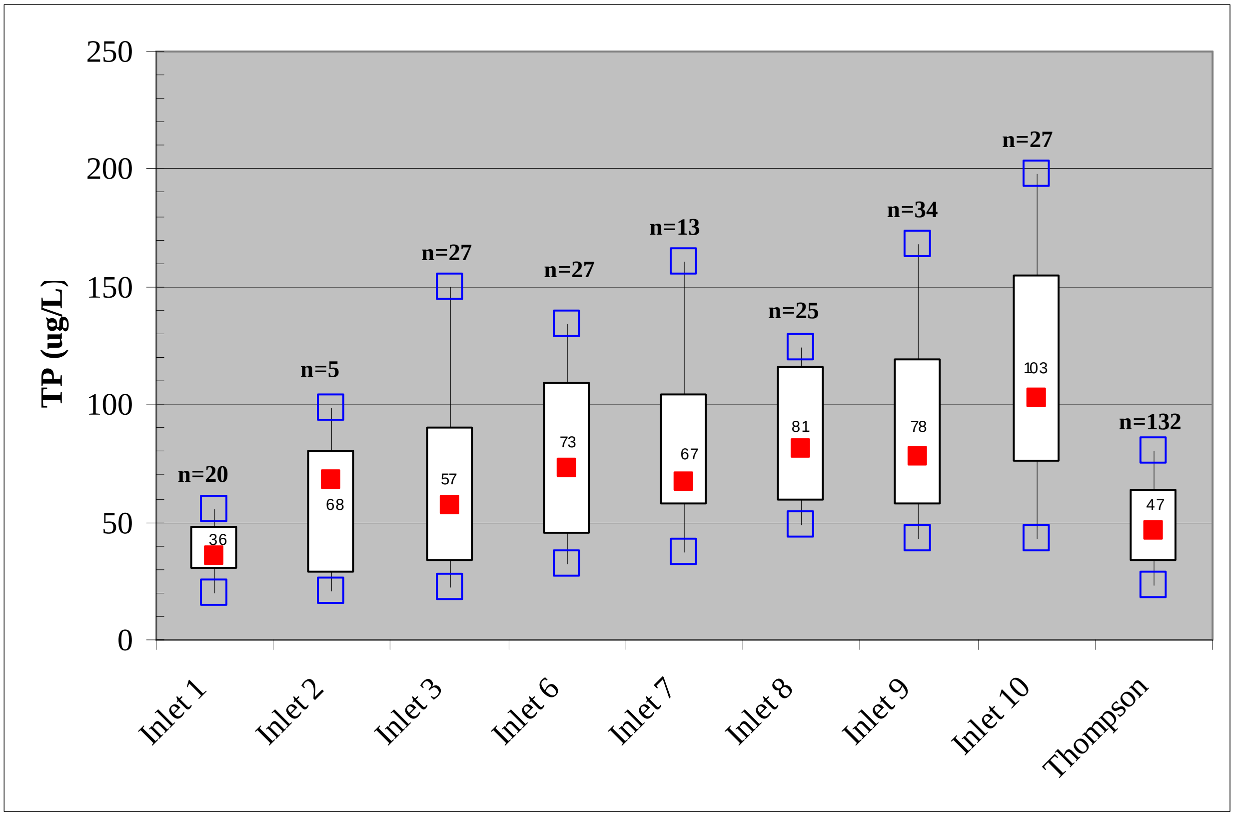

Figure 13. Box plots of TP concentrations (ug/L) for the major drainages to Newman Lake along with the number of samples collected (n).

On-site wastewater systems

The contribution of residential on-site wastewater systems to the external TP load was estimated using the following method. A 2004 land use survey determined that there are 571 residences surrounding Newman Lake with 61 percent, or 350 residences only used seasonally with the remaining residences (221) used year round. It was assumed that seasonal use extended from June though September. During this period, assuming a population per residence of 2.5, the residential population is approximately 1428. For the rest of the year (October through May), the residential population is estimated at 553.

From a daily average per capita water use of 60 gallons (0.23 m^3) and average domestic wastewater TP levels of 10 mg/L (Metcalf and Eddy, 1991) results in an annual loading rate of 0.8 kg TP/capita-yr. This TP loading rate for septic systems falls within reported levels (Reckhow, 1983).

So during the seasonal use period, based on a population of 1428, the TP load is:

$$(1428 \text{ capita})*(0.8 \text{ kg TP/capita-yr.})*(0.33 \text{ yr}) = 377 \text{ kg TP}$$

While for the rest of the year:

$$(553 \text{ capita})*(0.8 \text{ kg TP/capita-yr})*(0.67) = 296 \text{ kg TP}$$

These amounts are estimates of the quantity of TP associated with wastewater discharged to settling tanks prior to soil treatment. It is, however, assumed that there is minimal loss of TP within the settling tank, what TP is delivered to the septic tank is eventually discharged to soils.

Soil treatment varies in its effectiveness in adsorbing phosphorus and preventing it from entering the lake through groundwater transport. To express this process, a soil retention coefficient was applied. The coefficient can range from 0, indicating no retention of phosphorus, to 1, indicating complete retention. Under ideal conditions soil retention rates above 90 percent have been found (Gilliom, 1982). Retention rates will vary seasonally depending on soil saturation levels. Lower levels of phosphorus migration and introduction to the lake would be expected during the dry summer months than following snowmelt and storm events during the spring. To effect this seasonal retention variation, a weighting factor was applied.

Initially, an overall retention coefficient of 0.85 was assumed. In other words, it is assumed that on an annual basis 15 percent of the total phosphorus associated with on-site wastewater systems migrates to the lake. Based on the estimate for Honeymoon Bay, actual retention levels will be considerably lower in some locations surrounding the lake but under more ideal soil conditions, higher retention levels are expected. For this reason, the 0.85 retention level provides a conservative estimate for the Newman Lake setting.

Median monthly precipitation levels were determined from levels observed from 1985 to 2004 at the National Weather Service station located at the Spokane International Airport, approximately 37 kilometers southwest of Newman Lake. The monthly median levels were then divided by an overall annual median to provide a weighting factor. The factor described how each month's precipitation level compared to the overall monthly median. Factors varied from median levels of 0.3 (June – August) to 1.4 (December - January). These factors were then multiplied by the assumed overall migration level (15 percent of on-site TP) to determine monthly migration levels.

Because the annual estimate of TP attributed to on-site systems is based on seasonal populations, two migration levels were determined, one applying June through September, and the other October through May. The seasonal migration level (based on the median of the monthly values) was determined with June – September having a migration level of 0.05 and October through May, 0.17.

From these numbers, an estimate of the levels of TP introduced to Newman Lake can be determined. But the result is a constant level of phosphorus introduction varying only by season while in reality there likely is considerable variation, with the primary variable being soil saturation conditions. To effect this variation, observed monthly precipitation levels were again used.

Initially, the sum of monthly total precipitation levels observed during June-September and October-May were determined for each year from 1985 - 2004. From each of these seasonal precipitation datasets, the overall median was determined. Each period's annual precipitation level was divided by the overall median to determine a weighting factor. The factor provides a comparison of the precipitation level observed each year, for each period, with the overall median. The wetter years will therefore have a greater introduction of phosphorus than drier years. The result is that June-September TP introductions associated with on-site systems ranged between 9.0 kg to 42.7 kg, with a median of 19.8. For the period, October through May, the magnitude of TP migration ranged between 34.7 kg to 90.5 kg, with a median level of 51.1 kg. The total median level of TP discharged to Newman Lake from on-site system was 70.9 kg annually. This analysis provided an estimate of the TP associated with wastewater migrating to Newman Lake from 1985 to 2004 for each year's two analysis periods.

The monthly precipitation totals for each year were grouped into two sets each covering the two periods used to analyze the on-site TP loads, June through September and October through May. Total precipitation levels were determined for each of these periods and the percent of each period's total represented by month was calculated. These percentages were then used to distribute the annual loads on a monthly basis. For example, in 1985/86 the total precipitation level from October through May was 8.45 inches. In January 1986 the precipitation total was 0.38 inches, representing 4.5 percent of that season's annual total. The TP load for October through May of 1985 was estimated to be 34.7 kg. So in January, the estimated TP load from on-site systems was 1.6 kg.

As it will be discussed, one of the TP model assumptions was that groundwater inflow and, therefore, the TP load associated with groundwater, equaled that lost by groundwater outflow. Land use for the majority of Newman Lake's watershed is forestry, an activity that has a low influence on groundwater quality, particularly TP concentrations. For this reason, the only significant influence to groundwater quality is that associated with residential land use and, in particular, on-site systems. For this analysis, the contribution of on-site wastewater treatment to the TP external load serves as an assessment of the groundwater component to the overall external load.

Because surface water inflow samples were collected just above their discharge point to the lake, it is likely that observed TP levels are, in some instances, influenced by onsite discharge. Inlet 10 is an example of this influence.

Precipitation

Monthly precipitation totals, collected between 1985 and 2004 at the National Weather Service station located at the Spokane International Airport, approximately 37 kilometers southwest of Newman Lake, were used to calculate inflow associated precipitation. Inflows were calculated by multiplying the monthly rainfall amounts by the surface area of the lake (515 hectares).

Precipitation was assumed to have a TP concentration of 40 ug/L. This concentration was based on reported TP export coefficients for precipitation (Reckhow, 1983). The TP export coefficient used was 0.15 kg/ha-yr, a relatively low level within the potential range of reported values, reflective of the lake's rural setting. Based on an average annual precipitation level of 38 centimeters (14.8 inches) falling over the lake surface (515 hectares) the average annual inflow volume associated with precipitation is 1,929,353 m^3. Multiplying the precipitation export coefficient by the lake surface area results in an estimate of the average annual level of TP associated with precipitation.

$$(0.15 \text{ kg TP /ha-yr}) * (515 \text{ ha}) = 77 \text{ kg TP/yr.}$$

When this annual load is divided by the annual volume the result is a concentration of 40 ug/L.

$$((77 \text{ kg TP/yr})/(1{,}929{,}353 \text{ m}^3))*10^6 = 40 \text{ ug/L}$$

This concentration level was then applied to all precipitation volumes over the analysis period 1985 to 2004.

Overview of External TP Loads

Table 7 presents the estimated annual and summer period TP loads (in kilograms) by source from 1986 to 2004. Internal recycling was estimated through the TP model which will be presented in the next section. It is presented here as a comparison to the external TP sources.

Table 7. Estimated summer (June through August) and annual (September through August) TP loads (in kilograms) associated with surface water inflow, precipitation, on-site systems and internal recycling.

Year	Thompson Creek		Watershed		Precipitation		On-Site Systems		Total External Load		Internal Recycling	
	Sum.	Ann.	Sum.	Ann.	Sum.	Ann.	Sum.	Ann.	Sum.	Ann.	Sum.	Ann.
1985	45		36		5		8		94			
1986	36	408	29	331	5	78	8	75	78	892		
1987	36	387	29	313	23	81	34	88	122	869		
1988	35	282	28	229	7	73	10	66	80	650		
1989	34	391	28	317	12	88	18	87	92	883		
1990	121	440	98	357	26	89	38	93	283	979		
1991	71	445	57	361	9	74	14	69	151	949	184	346
1992	13	234	11	190	14	62	21	62	59	548	164	300
1993	46	321	37	260	18	81	28	82	129	744	156	300
1994	14	199	12	161	5	48	7	45	38	453	141	256
1995	45	654	37	529	19	103	28	101	129	1387	201	363
1996	86	705	69	571	12	100	18	99	185	1475	197	365
1997	181	1452	147	1177	8	116	11	106	347	2851	295	543
1998	125	728	102	590	7	76	10	72	244	1466	203	379
1999	107	979	87	794	12	83	19	79	225	1935	209	388
2000	111	881	90	714	6	78	9	70	216	1743	206	380
2001	33	328	27	265	8	51	12	52	80	696	170	312
2002	57	634	46	514	14	73	22	72	139	1293	195	361
2003	35	514	29	417	3	74	5	67	72	1072	154	279
2004	25	303	20	240	15	75	22	75	82	693	158	292
Median												
86-04	**45**	**440**	**37**	**357**	**12**	**78**	**18**	**75**	**129**	**949**		
91-04	**52**	**574**	**42**	**466**	**11**	**76**	**16**	**72**	**134**	**1183**	**190**	**345**
Record	**36**	**408**	**29**	**331**	**12**	**76**	**18**	**72**	**92**	**892**	**164**	**300**

Of the external loading sources examined on both a summer (June through August) and annual (September through August) basis, Thompson Creek comprises the greatest source of phosphorus to Newman Lake. During the summer period Thompson Creek, watershed drainage, precipitation, and on-site systems comprise 40 percent, 33 percent, 11 percent and 16 percent, respectively of the external TP load. A similar representation is observed on an annual basis at 47 percent, 38 percent, 7 percent and 7 percent.

The relationship between the estimated annual external loads and observed TP concentrations was examined (figure 14). As mentioned earlier, the median summer epilimnion concentration, for the years data have been collected, is approximately 20 ug/L. Applying the linear relationship presented in figure 14, an annual external load that results in a concentration of 20 ug/L is 899 kg. In comparison, the median summer period external load for the select years used in the regression analysis (data collection record) is 892 kg while the median estimated from 1985 to 2004, is also 892 kilograms (table 7).

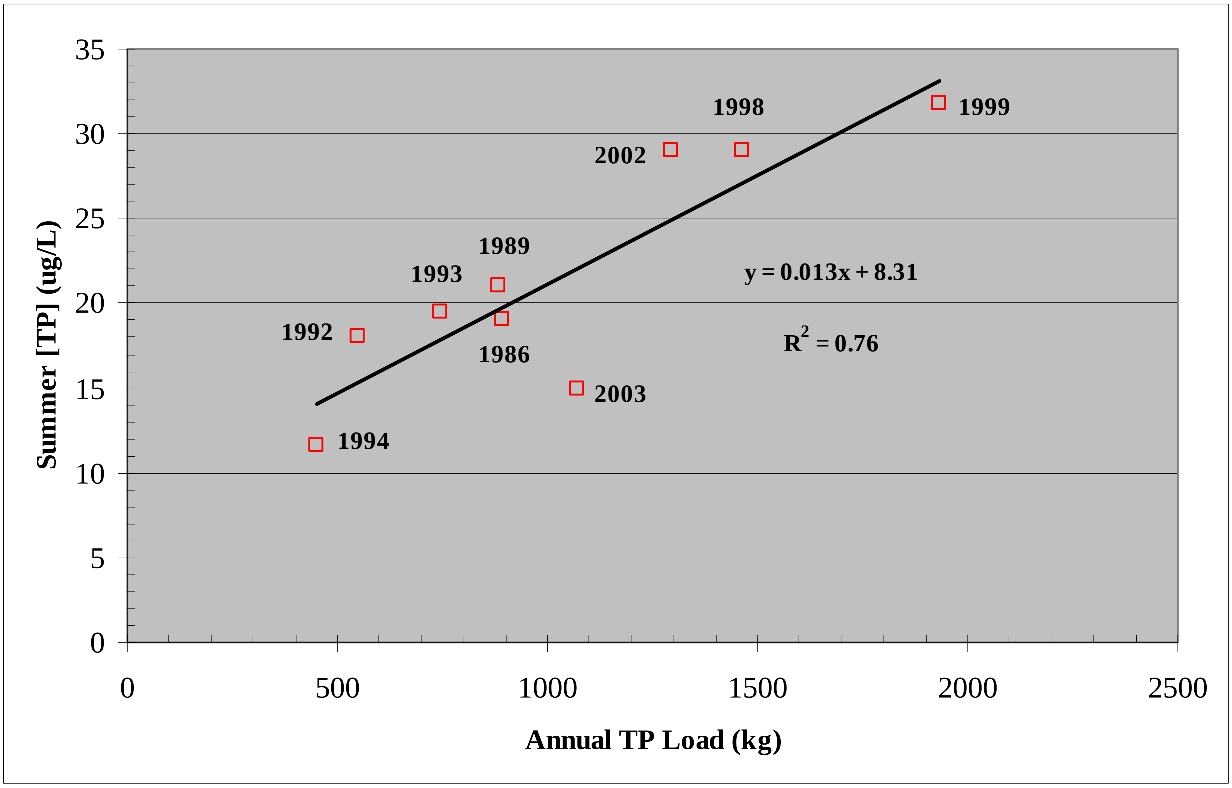

Figure 14. The relationship between the estimated September-August TP external load and the median summer (June-August) TP concentration observed in the epilimnion.

Relationship of Summer to Annual TP Load

During the summer period, the level of the external TP load has a direct effect on the epilimnion TP concentration. The majority of the inflow of phosphorus to Newman Lake occurs during months beyond the June through August period. Figure 15 displays the relationship between the summer and annual TP load. The summer period is June through August while the annual load is the period from September to the following August and so it spans from lake turnover through the end of the following years stratification period. As observed from figure 15, there is a close relationship between the magnitude of the summer and annual TP loads. Years with high spring inflow, the result of increased snowpack, maintain higher inflow levels during the summer. Deviations to this generalization occur most prominently in 1990 when inflow rapidly increased in June and remained elevated throughout the summer. Figure 16 displays the relationship between the annual and summer TP load from 1985 to 2004 for Newman Lake. From this relationship, approximately 12 percent of the annual TP load is delivered during the June through August period.

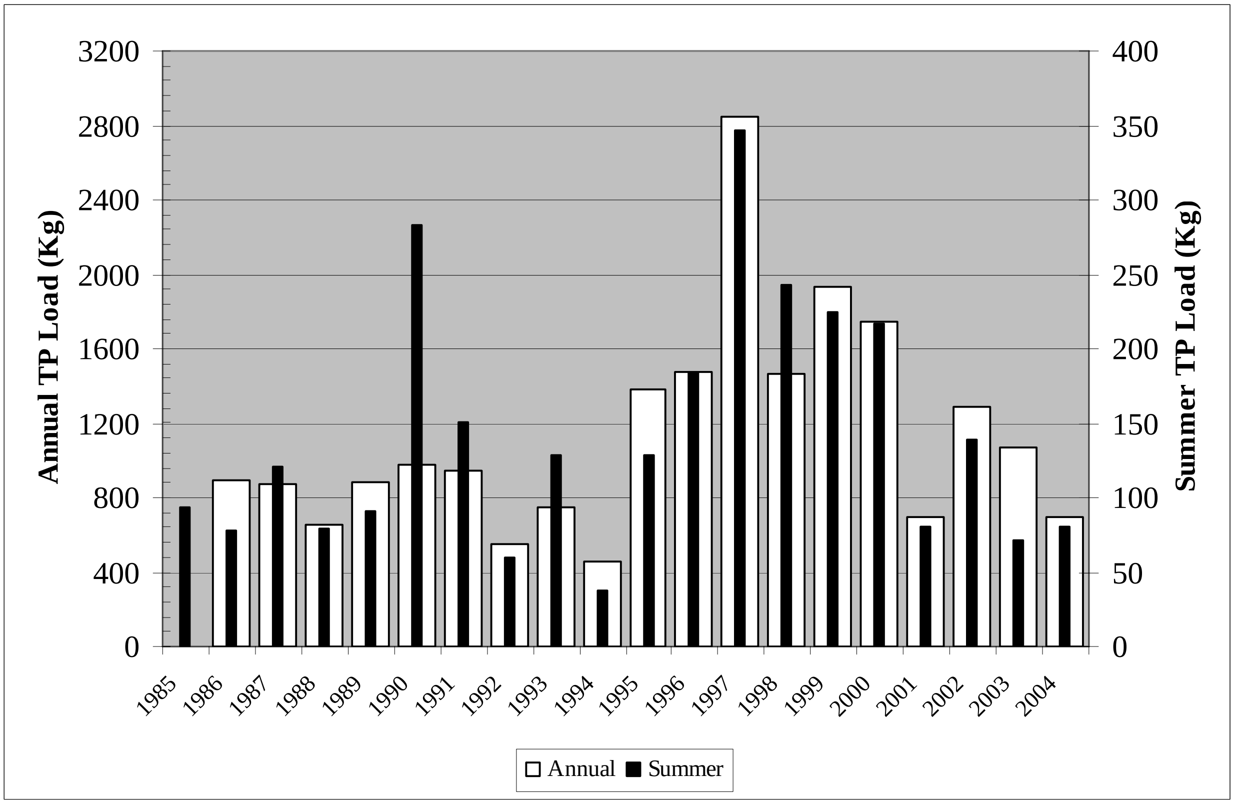

Figure 15. Relationship between the annual (September through August) in relation to the summer (June through August) external TP load (kg).

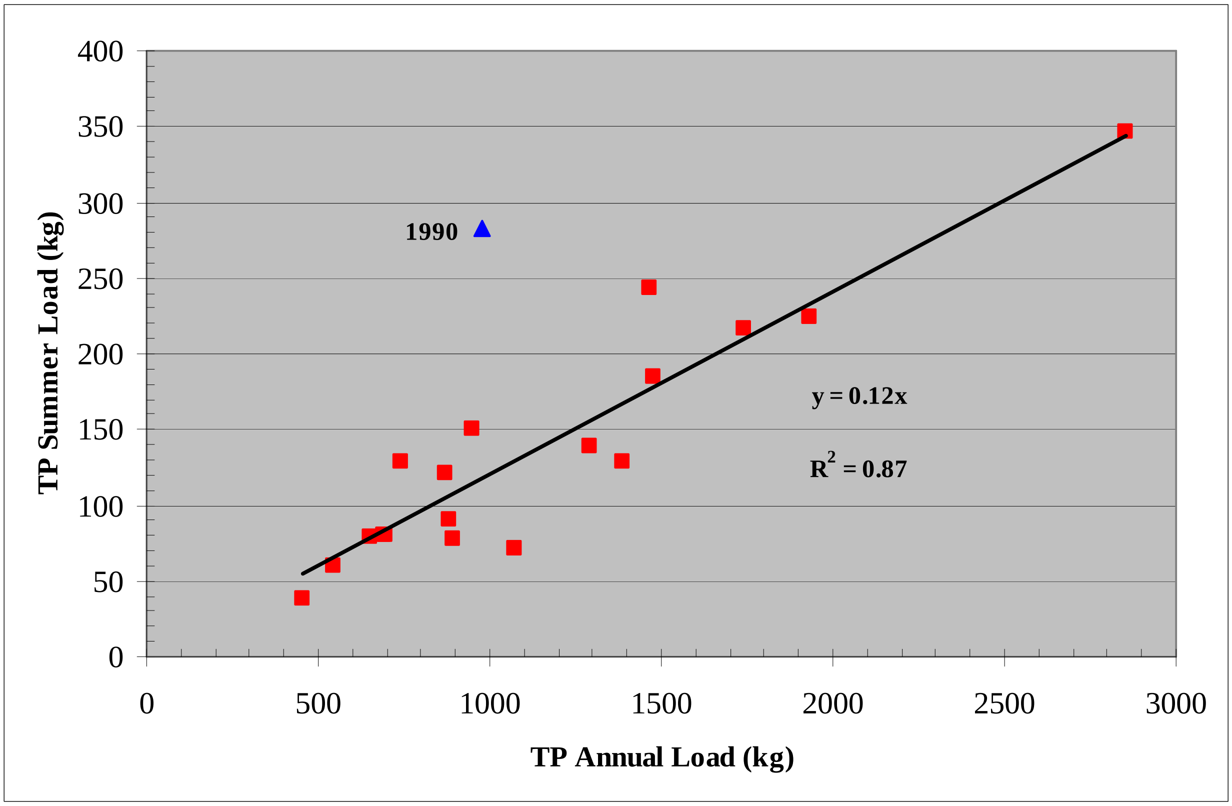

Figure 16. Relationship between the annual (September through August) and summer (June through August) TP loads.

TP Model

A mass-balance TP model was constructed to simulate Newman Lake's epilimnion and hypolimnion concentrations from 1991 to 2004. This period was chosen because the aerator, installed in 1992, was assumed to create a new variable in the lake's phosphorus dynamics. The model used a daily time-step so that all of the phosphorus inputs and outputs of the prior day determine the following day's lake concentration. Components of the model and its principal assumptions are provided below and depicted in figure 17.

Morphology

The determination of Newman Lake's bathymetric relationships was required for the model. Initially, a bathymetric map of Newman Lake (figure 1), originally presented in Wolcott (1961) was scanned and the area associated with each depth interval determined. From the digitized map, the relationship between area and volume by depth was determined (Wetzel, 1991). This information is presented in figure 18. These relationships were used to establish volumes and areas for the epilimnion and hypolimnion.

Stratification was assumed to begin on May 1st and end on September 30th. During the period the lake was stratified, the epilimnion was assumed to extend from the surface to a depth of 4-meters. Based on this distinction, the epilimnion contained approximately 17,124,000 cubic meters (m^3) or 65 percent of the total lake volume. The hypolimnion was assumed to extend from 4-meters to the bottom containing approximately 9,381,297 cubic meters, or 35 percent of the total lake volume.

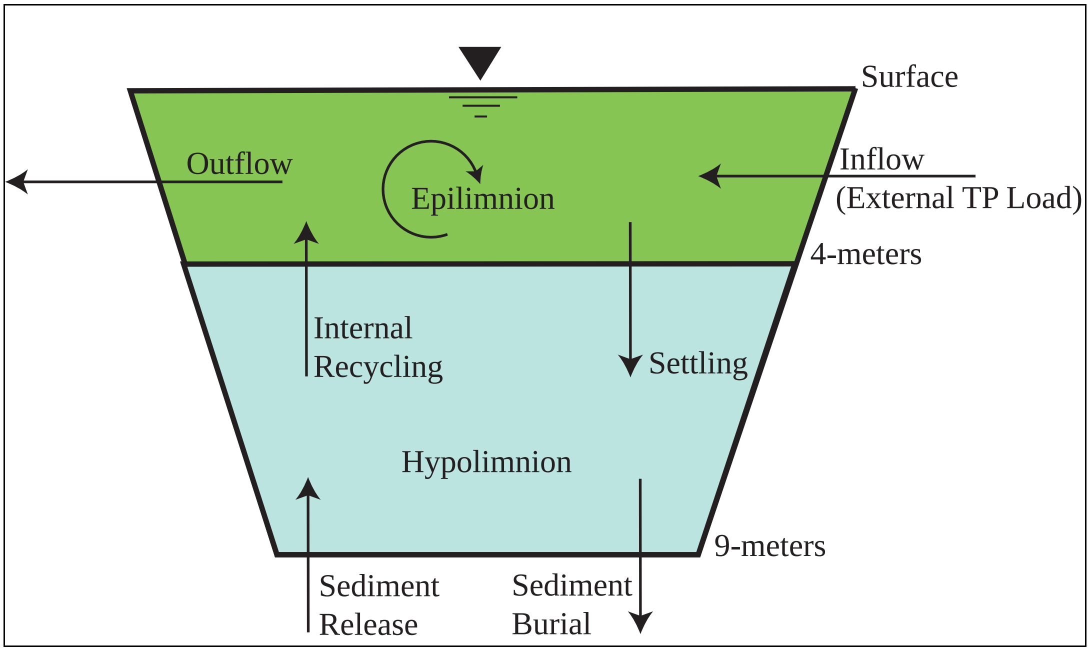

Figure 17. Components of the Newman Lake total phosphorus mass-balance model during the May through September stratified period.

In reality, the hypolimnion volume observed during the study period was situated below approximately 6-meters. However, the addition of another layer to the model that incorporated the metalimnion added a further level of complexity that extended beyond the data collected by prior investigations.

While the actual sections of the water column represented by the epilimnion and hypolimnion varied during the stratification period, particularly in the late-spring and early-fall, for the application of the model, it was assumed that the depths and volumes associated with this division remained constant throughout the stratified period. Each year, following the complete breakdown of stratification on October 1st, the lake was completely mixed and remained so until May 1st.

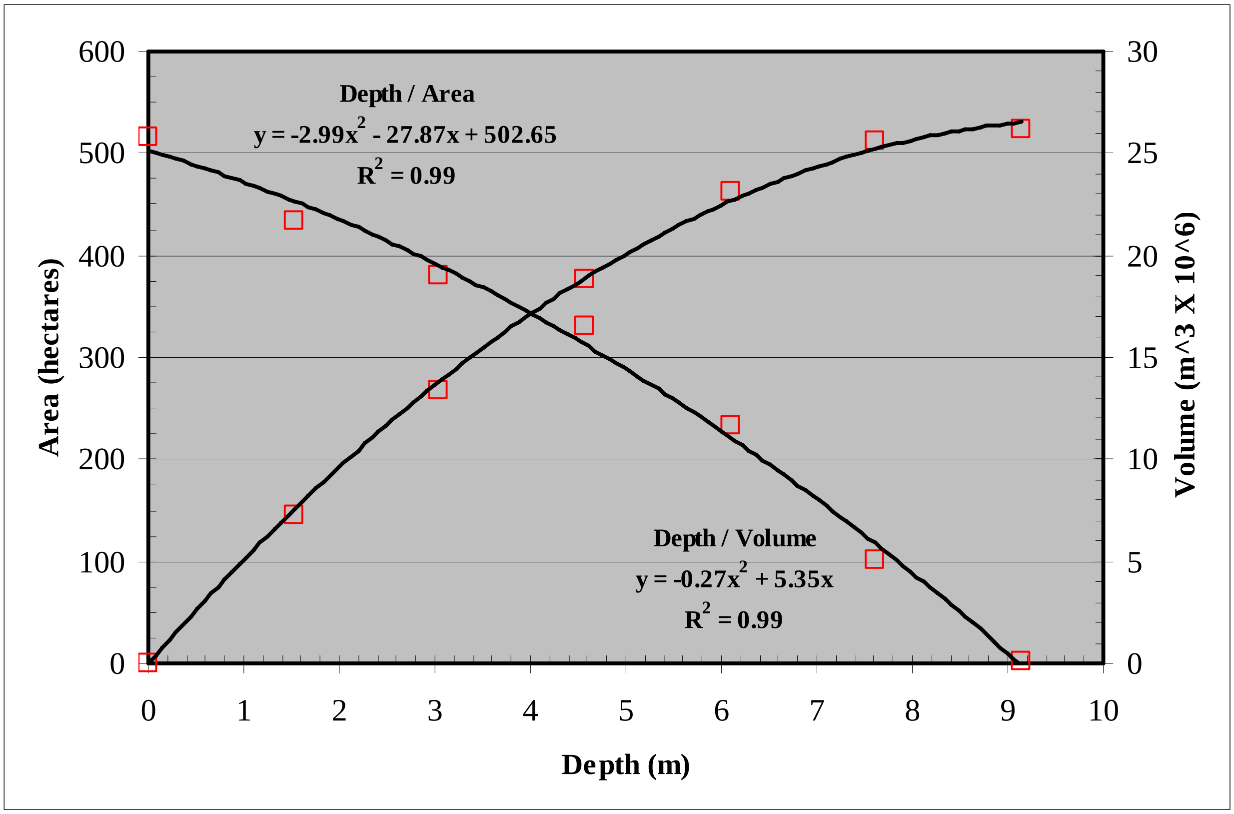

Figure 18. The relationship between Newman Lake's depth, surface area, and volume.

Epilimnion Layer

The epilimnion portion of the mass-balance model is represented by equation (1). The change in epilimnetic TP concentration with time is determined by the balance between the TP added from the lake's external and internal sources minus phosphorus associated with settling and outflow. All of these terms, which are in units of kilograms per day, are divided by the volume represented by the epilimnion. The resultant was multiplied by a factor of 10^6 to achieve units of micro-grams per liter per day (ug/L/d). A discussion of each of these terms is provided below.

Eq. 1. $dTP/dt = [\, W_{external} + W_{internal} - W_{settling} - W_{outflow} \,] / [\text{Epilimnion Volume}]$ *(ug/L-d)*

External Load ($W_{external}$)

The external load comprises the combined TP mass introduced to the lake from Thompson Creek and other surface water inflows, precipitation, and on-site waste water treatment systems. The TP loads associated with these sources were calculated using the methods discussed in the previous section.

Outflow (W_{out})

It was assumed that the level of outflow from Newman Lake equaled the inflow. Although the outflow from Newman Lake is controlled by an outlet structure, records of lake stage and outflow volumes were not regularly maintained. TP mass lost from Newman Lake through the outflow was determined in the model by multiplying the assumed outflow volume by the model-predicted lake TP concentration.

Settling (W_s)

Initially, an overall settling rate was calculated based on an annual steady state condition (Eq. 2). Annual settling velocities typically lie between 5 and 20 meters pre-year (m/yr) (Chapra, 1997).

Eq. 2. $[TP] = (L_{ext+int}) / (Q_{out} + vA_s)$

TP = steady state TP concentration (ug/L)
$L_{ext+int}$ = steady state TP load (kg/yr)
Q_{out}= steady state outflow level (m^3/yr)
v=settling rate (m/yr)
As=lake surface area (m^2)

Based on the TP data and loading determinations, both covering the period 1991-2004, an overall settling velocity (v) was calculated. A median annual volume-weighted TP concentration of 32 ug/L and a median annual inflow level of 18,115,997 m^3 were used as input to equation 2. The median annual external TP load calculated for 1991 to 2004 is approximately 1000 kg. If it is assumed that the component of the internal load lies between 0 and a level equal to the annual external load (1000 kg) then the calculated settling velocity lies between 2.6 and 8.8 m/yr.

In the initial model calibration process, a variable settling rate was used: one applying during the period of stratification (May through September); and another when the lake was completely mixed. For the majority of the stratified period, a settling rate of 0.58 meters per month (0.019 m/d, or 7 m/yr) was used. It was found during calibration that a settling rate of 7 m/yr also provided a good fit for the un-stratified period, October through April. This settling rate lies within the expected range.

To determine the mass of TP lost from the epilimnion through settling, the settling rate (meters per day) was multiplied by the settling area (5,026,500 square meters – surface area of the lake) and by the model-predicted TP concentration.

Internal Load (W_{int})

Phosphorus is introduced to the epilimnion from the hypolimnion through a process known as internal recycling. During the stratified period, the movement is through diffusion or the transport of TP from high concentrations present in the hypolimnion to the lower concentrations present in the epilimnion.

Similar to the settling term, internal recycling is difficult to accurately measure, for this reason one of the primary utilities of the model is its estimation. To calculate the TP load attributed to internal TP recycling, a sub-model was used that estimated a diffusion rate based on a vertical heat exchange coefficient (Eq. 3, Chapra, 1983).

The vertical heat exchange coefficient is based on the sequential difference in temperature between the epilimnion and the hypolimnion during stratification. Based on this analysis, an overall average diffusion rate of 0.2 m/d was used in the model from August 15th to September 14th. A vertical diffusion rate of 0.5 m/d was applied from September 15th to October 14th to reflect the increased movement of TP to the epilimnion associated with de-stratification. Diffusion of hypolimnetic phosphorus occurred each year from mid-August to mid-October. The hypolimnion and epilimnion TP concentrations, used to predict the load associated with diffusion, were based on model predicted values (Eq. 4).

Eq. 3. $U_t = (V_h/A_t*t_s) * Ln\,(T_{h\text{-}initia)} - T_{e\text{-}avg}) / (T_{h\text{-}final} - T_{e\text{-}avg})$

Ut = vertical diffusion coefficient (m/d)
V_h = hypolimnion volume (9,381,297 m^3)
A_t = surface area of thermocline (3,433,628 m^2)
$T_{h\text{-initial}}$ = thermocline temperature at onset of stratification (C^o)
t_s = time following $T_{h\text{-initial}}$ (d)
$T_{e\text{-avg}}$ = average temperature of epilimnion over stratification period (C^o)
$T_{h\text{-final}}$ = thermocline temperature at time of analysis (C^o)

Eq. 4. $Diffusion = [U_t * A_t*(TP_h - TP_e)(kg/d)$

Ut = vertical diffusion coefficient (m/d)
A_t = surface area of thermocline (3,433,628 m^2)
TP_h = hypolimnion concentration (ug/L)
TP_e = epilimnion concentration (ug/L)

Hypolimnion Layer

The parameters used to calculate the change in the hypolimnetic TP concentration are presented in equation 5. The change in hypolimnetic TP levels are based on the balance between the additions of phosphorus associated with sediment release and settling (equivalent to the settling loss from the epilimnion) with losses through sediment burial and internal recycling to the epilimnion. Shared between the epilimnion and hypolimnion layers of the model are the diffusion and settling pathways. A further explanation of each of the equation terms is provided below.

Eq. 5. $dTP/dt = [\, W_{srr} + W_s - W_b - W_i \,] / [\, V_h] \,(ug/L)$

W_{srr} = sediment release rate (kg/d)
W_s = settling (kg/d)
W_b = burial (kg/d)
W_i = internal load (kg/d)
V_h = hypolimnion volume (m^3)

Settling (W_{settle})

The TP settling term is shared between the epilimnion and hypolimnion layers of the model. For this reason, this term is equivalent for each of the model layers for each time-step. As TP settles and leaves the epilimnion it enters the hypolimnion. So the loss of TP through settling in the epilimnion is a gain to the TP mass in the hypolimnion.

Burial (W_{burial})

For model application, the burial rate of phosphorus in the hypolimnion was determined based on sediment core samples analyzed for TP (Funk, 1976).

Sediment samples were collected from depositional areas within the lake (depths greater than 6-meters). On average, the sediment phosphorus content within the upper 30-centimeters of the sediment averaged 0.00175 kg TP/kg sediment (or approximately 0.18 percent). Phosphorus concentrations drop sharply at the 60-centimeter depth. Between 60 cm to the bottom of the core at 75 cm, the phosphorus concentration was observed at an average level of 0.00101 kg TP/kg sediment (dry weight). The expected level of TP within un-impacted sediments is approximately 0.1 percent displayed by sediment quality observed below the 60 cm depth. The upper 10-cm of a soil sample collected in a forested (un-impacted location) was found to have a percent TP level of 0.06 percent (Funk. 1976).

Based on historic activities surrounding Newman Lake significant changes to the lake's watershed began around 1900: hydraulic mining occurred in Thompson Creek (late 1880s); several sawmills begin operation situated along the lakeshore (1887-1927), logging occurred within the watershed to supply the mills; and in the 1920s recreational development occurred with six resorts located along the lake. So right around 1900 numerous activities within Newman Lake's watershed resulted in increasing TP loading.

Assuming that the change in TP content observed at the 60-centimeter mark of the core is the result of these changes and occurred around 1900 then the long-term average sedimentation rate is approximately 0.79 cm/yr (0.0079 m/yr). Assuming a water content of 93 percent water (7 percent solids) and a depositional area of 1,010,000 square meters (25-foot isopleth in figure 1) and applying the sedimentation rate of 0.0079 meters per year, the annual burial, or retention of phosphorus, is approximately 977 kilograms per year.

(0.0079 m/yr)*(1,010,000 m^2)*(0.00175 kg TP/kg Sediment)*(1000 kg/m^3)*(0.07) = 977 kg TP/yr

The volume below the 25-foot contour serves as a trough within the lake between the inlet and the outlet. For this reason, sediments deposited throughout the lake would eventually migrate or focus below this depth (refer to figure 1).

This long-term level of phosphorus retention served as a guide to estimate the burial velocity. The magnitude of the burial velocity was set to effect a similar TP annual retention level over the analysis period. Two burial velocities were used; one applying for the stratified period (May through September) and the other for the un-stratified period. For the stratified period, a burial velocity rate of 4 m/yr or 0.011 m/d was applied. For the rest of the year a rate of 10 m/yr or 0.027 m/d was applied. It is recognized that this rate is a long-term average and that phosphorus migration within the surficial sediments does occur (meaning retention does not preclude continued interaction with the water column).

These velocities resulted in a median TP burial level of 900 kg/yr for 1991 to 2004.

Eq. 6. *Burial =[Vb*At*TP$_h$]*

V_b = burial velocity (m/d)
A_t = surface area of thermocline (3,433,628 m^2)
TP_h = hypolimnion concentration (ug/L)

Internal load ($W_{internal}$)

The internal recycling load, or loss associated with diffusion, is the mass transfer of TP from the hypolimnion to the epilimnion. Similar to the epilimnetic settling term (W_s), this component is shared between the two layers and therefore, is equivalent in magnitude for each time-step. For the hypolimnion, diffusion and entrainment is a loss while, as discussed earlier, for the epilimnion it is a gain in TP mass.

Sediment Release Rate ($W_{sediment\ release}$)

The factors used to determine the sediment release rate are presented in equation 7. The sediment release rate is based on the difference in hypolimnetic TP levels between successive sampling events divided by the period (days) separating those events.

Based on this method, 200 kilograms of TP is released into the hypolimnion from sediments during the period July 15th to September 14th resulting in an overall release rate of 0.94 mg/m^2-d.

Eq. 7. *Sediment Release Rate* $(mg/m^2\text{-}d) = (V_h/A_t) * (C_f - C_i) / dt$

Vh = hypolimnion volume (9,381,297 m^3)
A_t = surface area of thermocline (3,433,628 m^2)
C_f = hypolimnion TP concentration at time of evaluation (ug/L)
Ci = hypolimnion TP concentration of prior sampling (ug/L)
dt = number of days separating observations (d)

Model Results

Calibration

Calibration was achieved for the epilimnion portion of the model through adjusting the sedimentation rate and, within the hypolimnion, through adjustment of the sediment release rate. Rates were set to provide the best overall fit between observed concentrations and model predictions over the entire analysis period, 1991 to 2004, not through annual adjustments. The model provided daily predictions of epilimnion and hypolimnion TP concentrations. Annual and seasonal adjustments to model rates could have provided a closer fit between observed concentrations and model predictions. However, leaving the rates fixed, varying only during the stratified and mixed periods, allowed for a more objective examination of the lake's phosphorus dynamics. So each rate used in the model is an overall average level that provides the best fit for the analysis period.

In addition to the sedimentation and sediment release rate, adjustments were also made to the amount of external loading occurring in 1994, 2003, and 1997. The TP external load for 1997 was increased by 50 percent while the loads for 1994 and 2003 were reduced by 50 percent to further facilitate calibration.

The relationship between predicted and observed summer period epilimnion and hypolimnion TP concentrations is presented in figures 19 and 20.

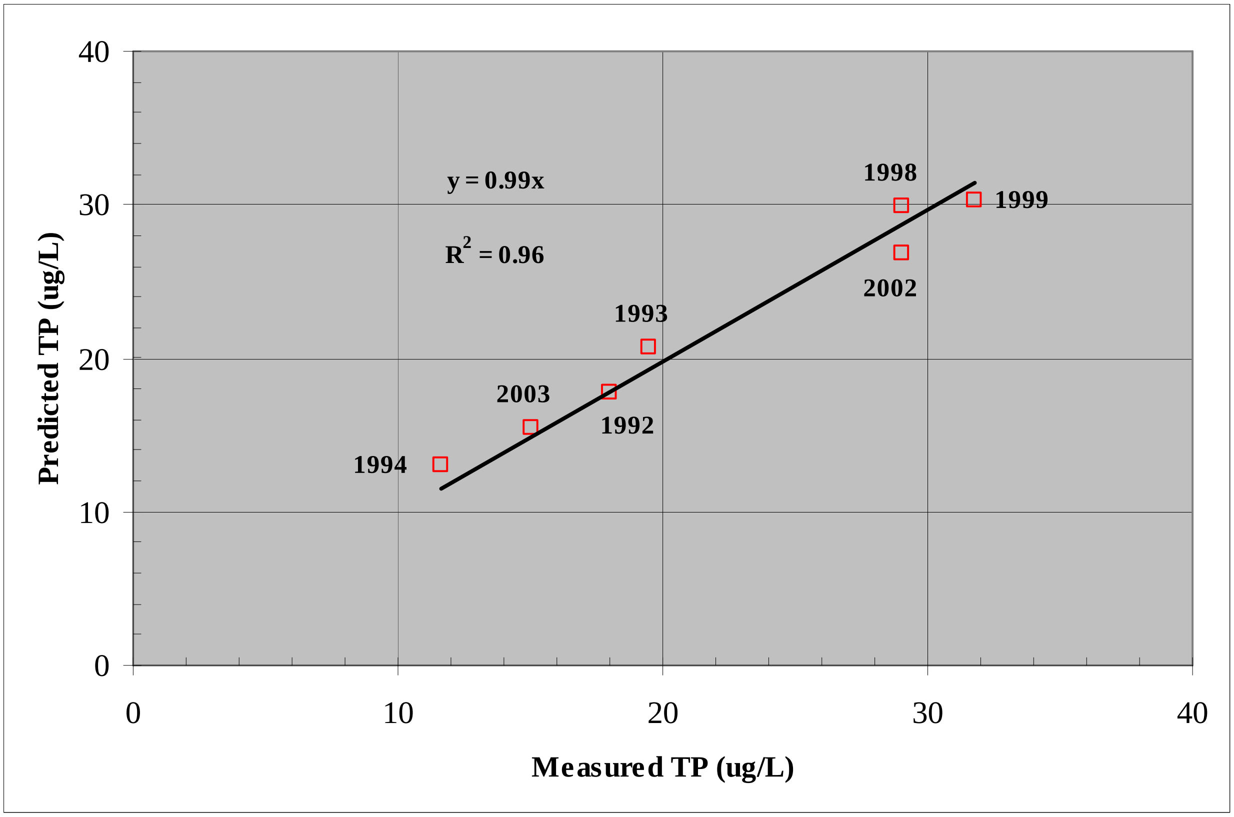

Figure 19. Relationship between measured and predicted epilimnion TP concentrations expressed as a June-August (summer) average.

The model provided a good fit for the summer period epilimnion concentrations with the slope of the best fit line approaching 1 and a coefficient of determination of 0.92 (figure 19). Model predicted summer average hypolimnion concentrations were also close to observed levels with a coefficient of determination of 0.68 and slope of 1 (figure 20). Based on individual observations of epilimnion TP concentrations collected during the June through August period, the model was biased. The slope of the best fit line was 0.9, indicating that the model predicts a lower TP concentration than observed by 10 percent (figure 21). Through the expected range in TP concentrations observed in Newman Lake this bias could lead to the under prediction of concentrations by 2 to 4 ug/L. However, the emphasis of the model calibration was on predicting summer average TP concentrations, the primary measure used in this TMDL.

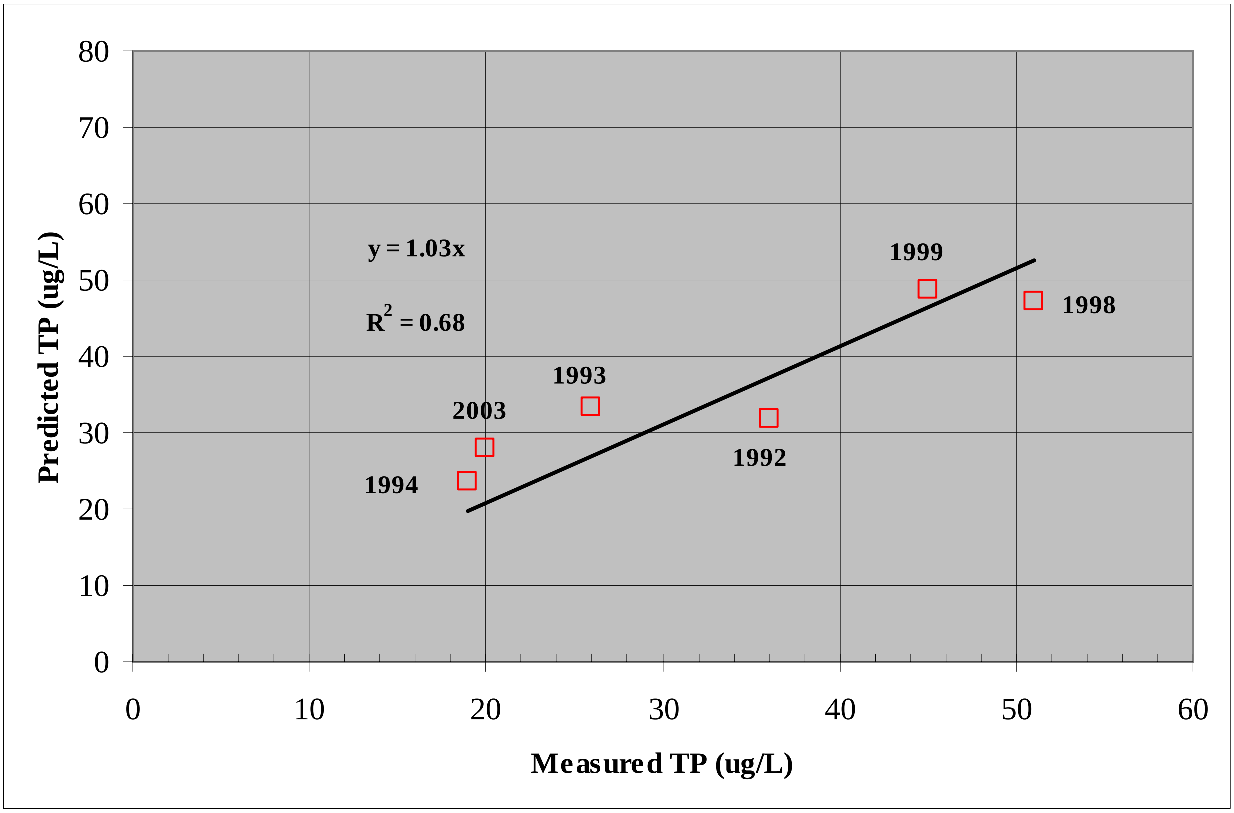

Figure 20. Relationship between measured and predicted hypolimnion TP concentrations expressed as a June-August average.

A comparison between the annual (September through August) external load and model predicted epilimnion TP concentrations (1991 to 2004) is presented in figure 22. The slope and y-intercept of the relationship are similar to those presented previously (refer to figure 15) based on select summer periods with available data.

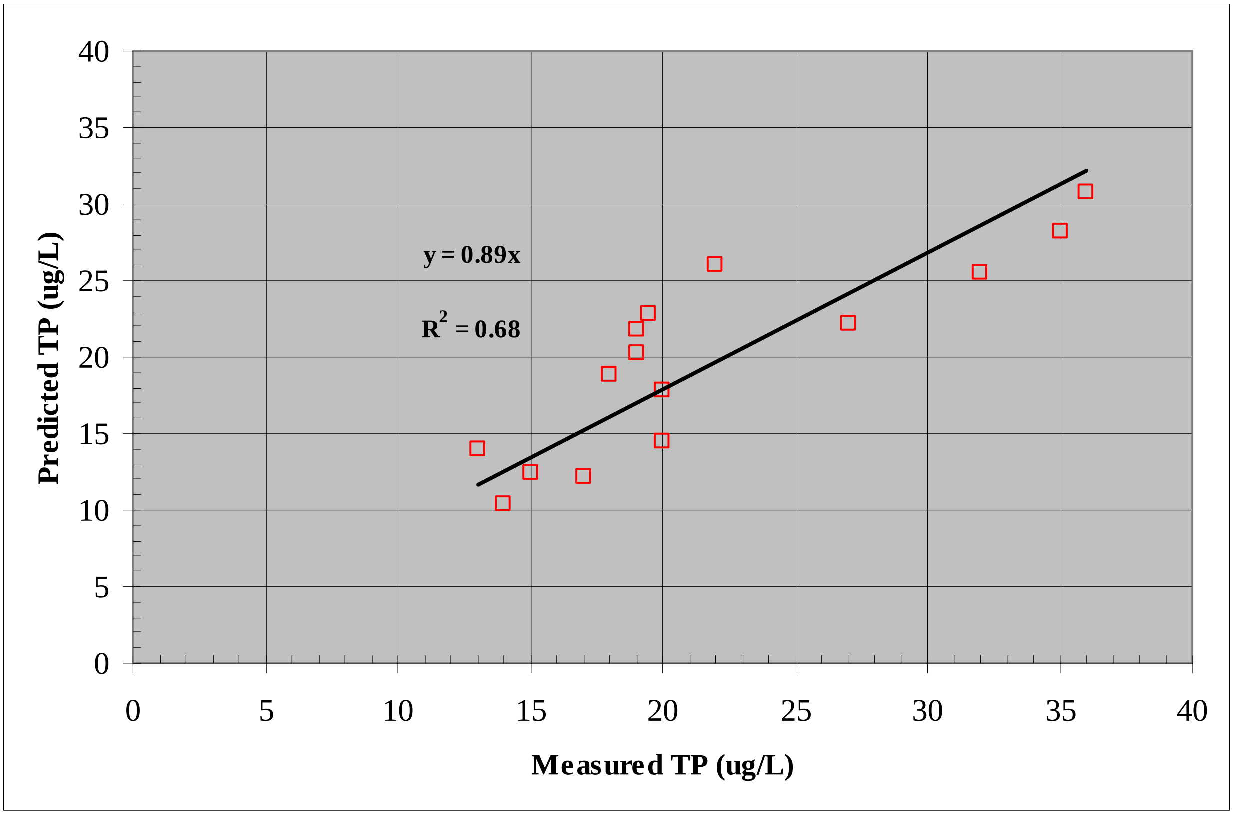

Figure 21. Relationship between measured and predicted epilimnion TP concentrations (ug/L) observed during the summer period.

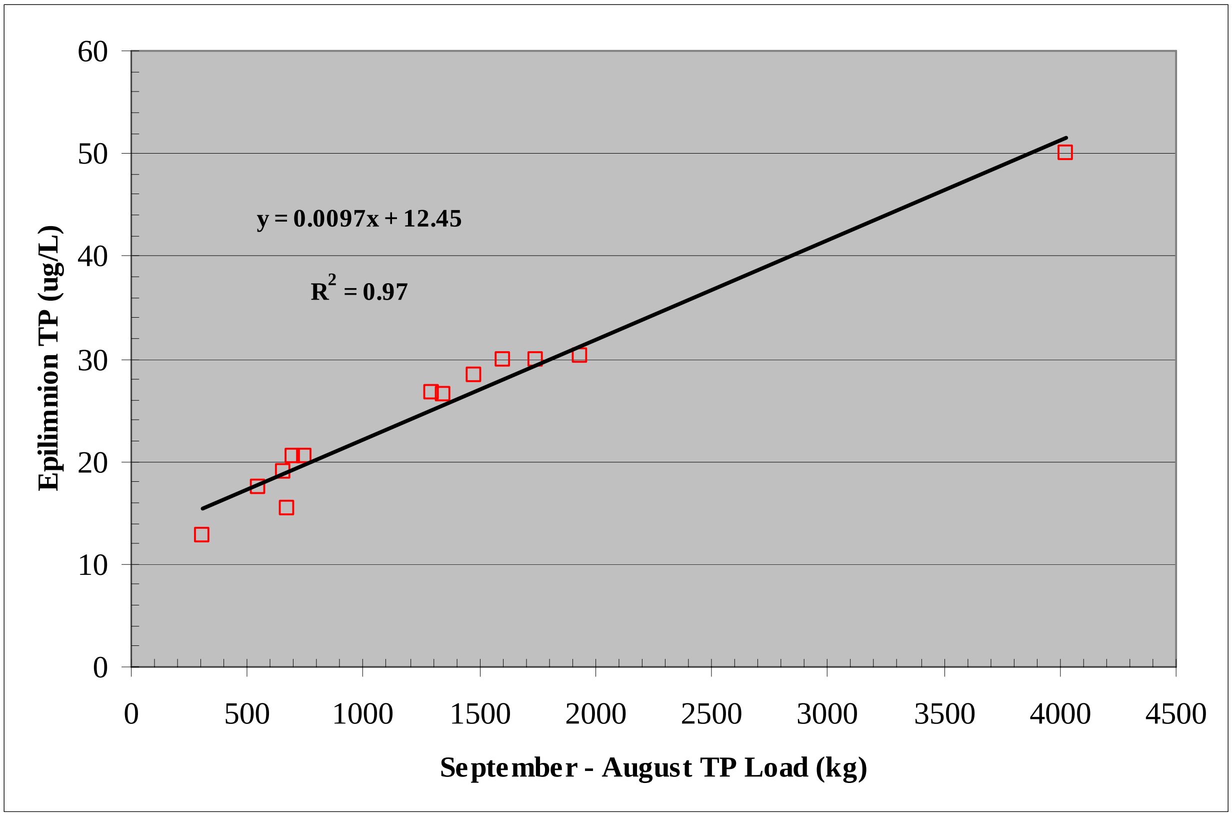

Figure 22. Relationship between the summer period TP load (kg) and the predicted epilimnion TP concentration expressed as a June-August average, 1992 to 2004.

Discussion of Model Results

Model results of predicted summer median epilimnion TP concentrations ranged between 13 ug/L in 1994 to 50 ug/L in 1997 (figure 23). The overall summer median for the 1991 to 2004 period is 26 ug/L. As presented earlier, there is linear relationship between the amount of phosphorus introduced from external sources and the average summer in-lake concentration (refer to figure 22). Years with greater external TP loads result in greater in-lake TP concentrations. In general, the level of spring and summer inflow is the largest determinant on summer period TP concentrations. Table 8 contains a hierarchical arrangement of the flow levels arranged by year for June through August and October through May periods. Summer periods with low inflow levels such as 1994, 2001, 2003, and 2004 had significantly lower epilimnion TP levels in comparison to summers with high inflow such as 1995, 1997, and 2002.

For Thompson Creek, from 1986 to 2004 there is a close relationship between winter-spring inflows, as indicated by the sum of the inflow from October through May, and summer period flows (June through August) (table 8, figure 24). The exception is 1990 and 1998 when disproportionately higher flow levels occurred during the summer period. Typically, higher spring inflow, indicative of greater snow accumulation, maintains flow at a higher level through the summer.

What this indicates is that TP concentrations within Newman Lake are highly influenced by the level of inflow and that this variability is also be reflected in observed lake TP concentrations.

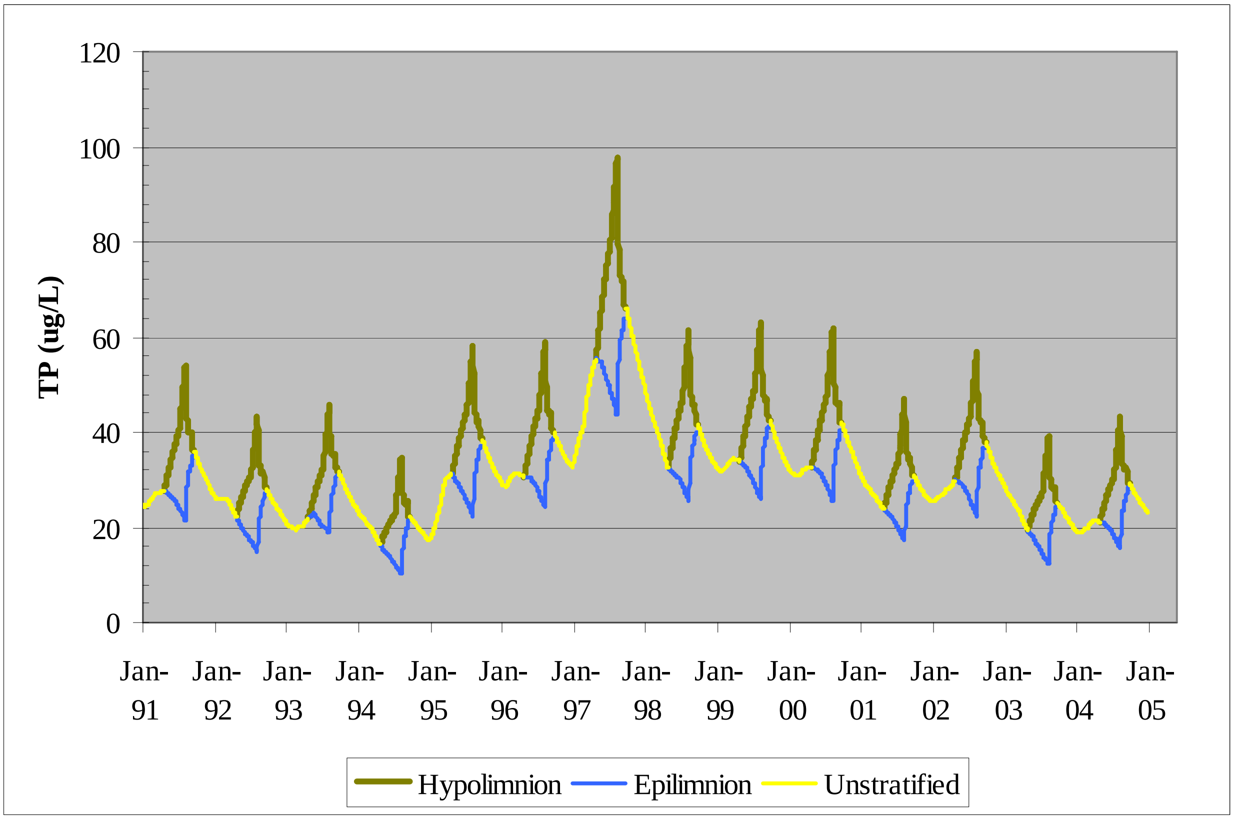

Figure 23. Model predictions of epilimnion and hypolimnion TP concentrations (ug/L) from 1991 to 2004.

Table 8. Thompson Creek flows arranged in ascending order for the summer and annual periods from 1986 to 2004.

Flow Levels																			
Low==High																			
Months	**Years**																		
6-8	92	94	04	01	89	88	03	87	86	95	93	02	91	96	99	00	90	98	97
10-5	94	92	88	93	04	01	90	87	89	86	91	03	98	02	95	96	00	99	97

One of the primary utilities of the model was to provide an estimate of internal TP recycling to the epilimnion. Table 9 includes TP budgets for the summer period June through August, the entire stratified period (May through September), and the fully mixed period (October through April) for 1991 to 2004.

Referring to figures 25 and 26 and, based on median concentrations observed during the summer period (1991-2004), the external and internal loads to the epilimnion comprise 41 percent and 59 percent, respectively of the total phosphorus load. While on an annual basis the external and internal loads comprise 76 percent and 24 percent, respectively, of the total load. However, internal recycling and external loading affect epilimnion concentrations differently. This is due primarily to the time each source influences epilimnion concentrations. Internal recycling is initiated from mid-August, associated with the erosion of stratification, while for the majority of the summer period (June to mid-August), external loading serves as the primary source of TP to the epilimnion.

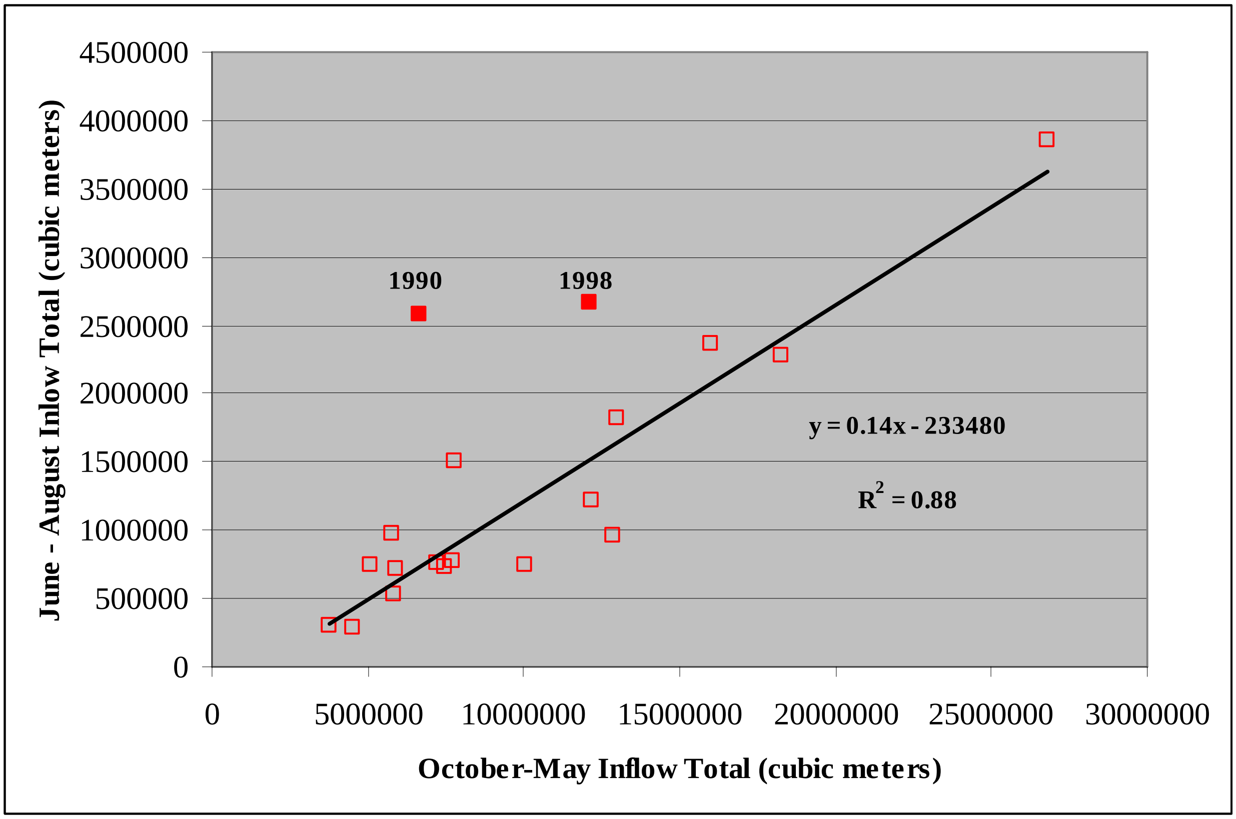

Figure 24. Relationship between October – May and June-August inflow estimated for Thompson Creek.

Table 9. Median TP loading estimates in kilograms (1991 to 2004) determined for the stratified period (May-September and June –August) and un-stratified period (October – April). TP sources are shaded blue and losses in white.

Analysis Period	External Loading	Outflow	Settling	Internal Recycling	Burial	Sediment Release
June-August (Stratified, Summer Period)						
Epilimnion	134	52	227	190		
Hypolimnion			227	190	142	155
May – September (Stratified Period)						
Epilimnion	277	118	421	334		
Hypolimnion			421	334	229	200
October –April (Unstratified Period)						
October - April	982	464			689	75

In terms of the nutrient budget, particularly during the summer period, internal recycling continues to be a major source of phosphorus to the epilimnion, comprising 60 percent of the total load (figure 25).

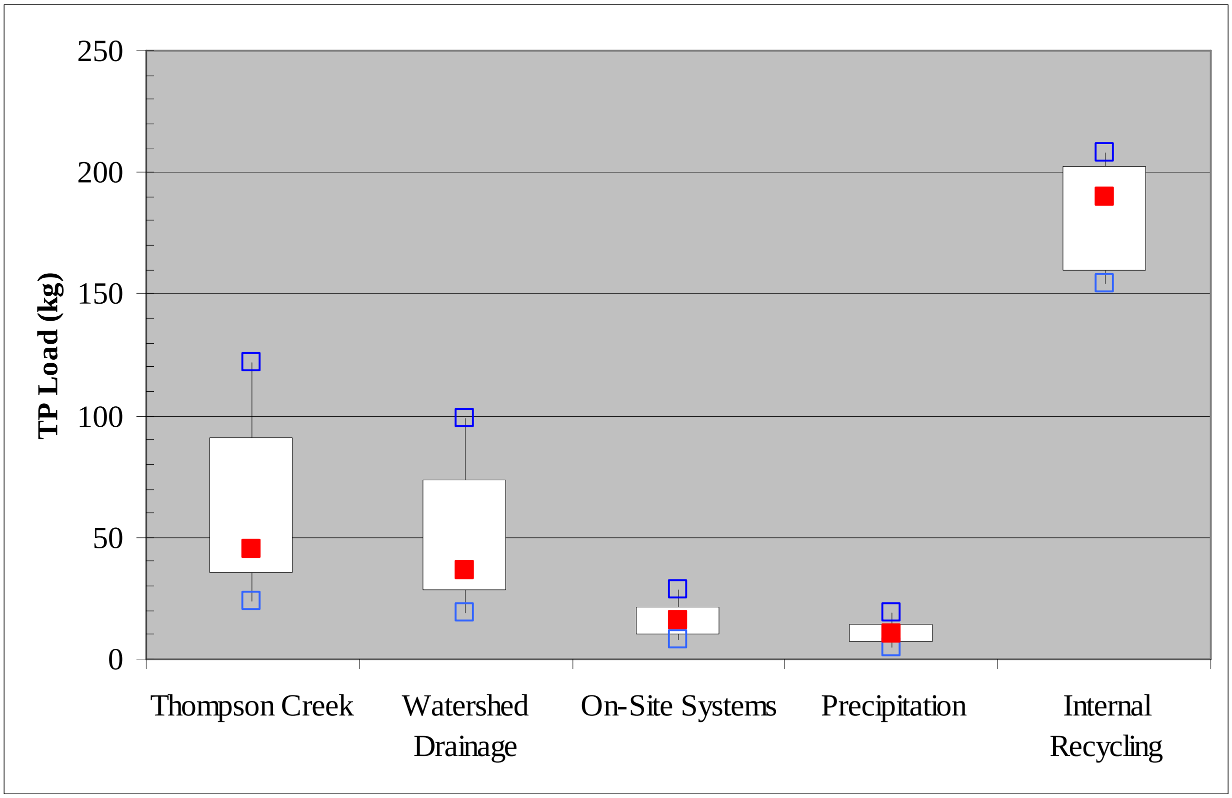

Figure 25. Box plots of June through August (summer) TP loading for the sources evaluated.

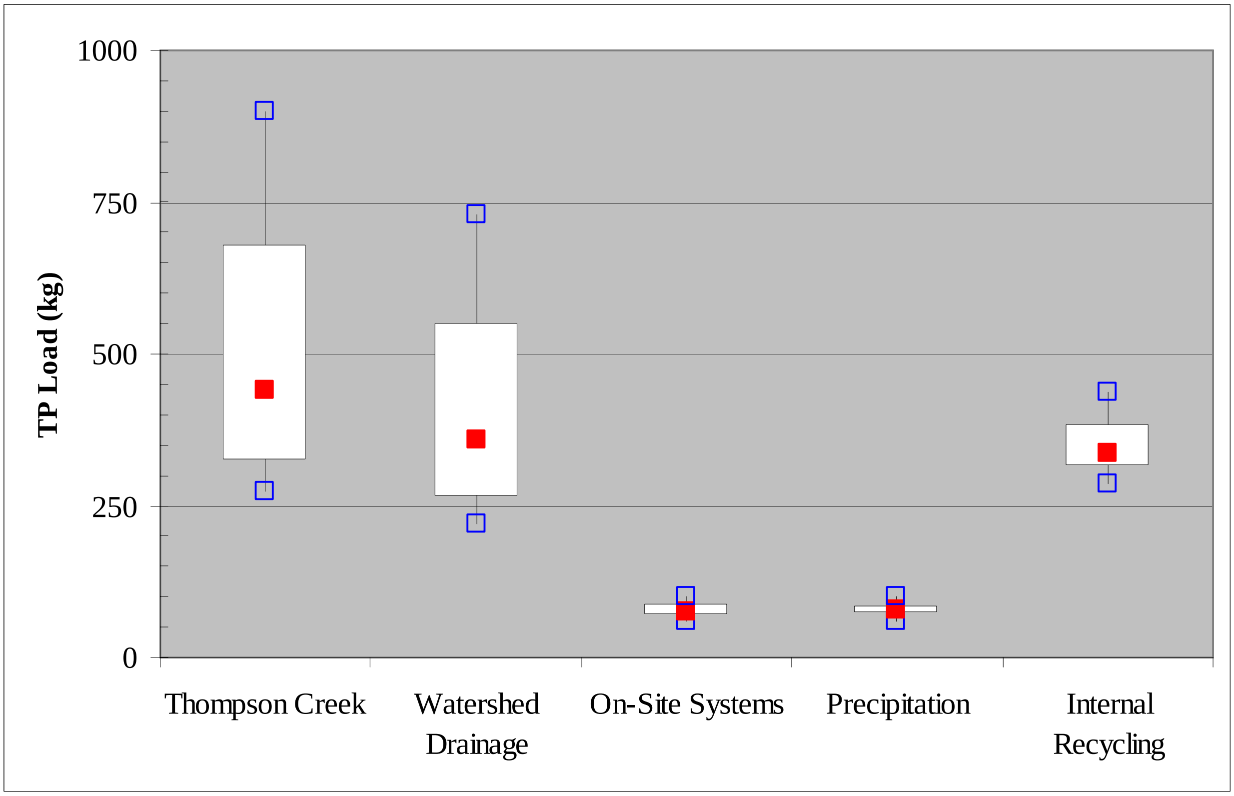

Figure 26. Box plots of September through August (annual) TP loading for the sources evaluated.

Though relatively infrequent, lake turn-over occurring during the summer period, the result of low pressure systems (cooler air and winds), can also result in recycling TP to the epilimnion. Because of the large influence external loading has on affecting summer period epilimnion TP concentrations and that in-lake restoration methods to control internal recycling are currently in place, this TMDL analysis focuses on the control of external TP loading as the means to improve water quality.

Loading Capacity

Establishing the Load Capacity

Within this TMDL, the load capacity is defined as the maximum amount of TP that can be introduced to the epilimnion from June through August while maintaining concentrations at or below 20 ug/L. The target concentration is set at a level that is protective of the beneficial uses of the lake for activities such as swimming, fishing, and boating. For this study, the critical period is June through August and the target concentration is the average TP epilimnion concentration observed during that period. Washington State Department of Ecology has suggested target TP concentrations for lakes based on their inclusion within specific eco-regions. Newman Lake is located within the Rocky Mountains eco-region and its suggested TP epilimnion target concentration is 20 ug/L. Because a margin of safety in achieving the target concentration is a required component of the TMDL analysis, the load capacity was set at a level that provides a 90 percent assurance that epilimnion concentrations will be at 20 ug/L or below in any given summer. The target concentration sets the ultimate water quality objective of the TMDL study. The load capacity and pollutant source allocations are all based on meeting the target.

Model Application for Establishing the Load Capacity

The mass balance model was used to establish the TP load capacity. Initially, percentiles of the annual (September–August) external TP loads were determined for the period of analysis 1992 to 2004. The external load was then reduced sequentially by 10 percent up to 100 percent reduction (no external load) (table 10). From the initial condition, and following each change in the external load, percentiles were determined for the predicted epilimnion TP concentrations, expressed as a summer median (table 11). So for instance, referring to table 10 for the current condition (0 percent reduction) the 50th percentile for the annual TP load is 1121 kg. The 90th and 10th percentiles are 1877 and 576 kg, respectively. Based on these loads, the corresponding epilimnion TP concentrations for the 90th, 50th, and 10th percentiles are 30.2 ug/L, 25.8 ug/L and 16.1 ug/L, respectively (table 11).

External TP loads from 1996 to 2000 were above average and so the percentiles generated for the model analysis period are greater in comparison to those estimated for 1986 to 2004. Though considering this period allows for a margin of safety in the analysis, a required component of the TMDL process. The reason for the differing analysis periods is that it was assumed that current in-lake management practices (aerator and alum injection) exert a significant enough change in the TP dynamics that data collected prior to its installation would represent a different condition. The external loads between 1997 and 2000 were among the highest estimated over the 20 year period external loads were estimated. This results in a bias towards the model's higher external loads and associated concentrations. However, the model provides a conservative approach to setting the load capacity.

In application, external TP loads (with the exception of TP associated with precipitation) were sequentially reduced by 10 percent and the summer average TP concentrations determined. For each change, percentiles were determined for the loads and concentrations over the analysis period: 1991 to 2004. A 40 percent decrease in the summer period external load results in a 50th percentile of 702 kg resulting in a concentration of 17.2 ug/L a decrease of approximately 33 percent. (The current (1991-2004) median concentration is 25.8 ug/L.) In addition, a 40 percent reduction in the annual external load results in a greater than 90 percent assurance median summer period concentrations are below 20 ug/L, the suggested eco-regional target concentration (table 11).

Based on these relationships, a 40 percent reduction in the external TP load provides a reasonable target for the TMDL. From the model predictions, the summer median TP concentration from 1991 to 2004, of 25.8 ug/L, would decrease to 17.2 ug/L. The current median (50th percentile) would be situated at the 95th percentile, a 45 percent reduction in occurrence providing for an increased margin of safety. This would provide a significant improvement in water quality and the load reduction, while ambitious, is within a level that is achievable. For these reasons, the load capacity for the external load is set at 702 kilograms. The load capacity level has been set based on median levels though the method incorporates the observed variability through the use of a margin of safety.

Table 10. Percentiles of the summer period external TP load associated with various reduction levels based on estimates determined for 1991 to 2004.

Summer Period External TP Load Changes 1991 - 2004											
	Percent Reduction in Load										
Percentile	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
100	4041	3648	3256	2863	2471	2078	1686	1294	901	509	116
95	2672	2414	2156	1899	1641	1383	1125	868	610	352	108
90	1877	1697	1518	1338	1159	979	799	620	440	261	102
85	1752	1584	1417	1249	1082	915	747	580	412	245	100
80	1660	1502	1344	1185	1027	869	710	552	393	240	90
75	1573	1424	1275	1126	977	828	679	530	380	236	82
70	1488	1349	1210	1071	932	793	654	515	376	230	81
65	1406	1275	1145	1015	884	754	623	493	363	228	79
60	1338	1214	1089	965	841	717	593	469	345	221	77
55	1301	1179	1056	934	812	689	567	445	322	200	77
50	1121	1016	912	807	702	597	493	388	283	178	76
45	918	834	750	665	581	497	413	328	244	160	75
40	785	715	644	573	503	432	362	291	221	150	74
35	723	657	592	526	461	395	331	268	204	141	74
30	694	630	566	502	438	374	312	252	193	133	74
25	677	616	555	494	433	373	310	248	190	133	73
20	660	602	543	485	426	367	307	246	186	126	69
15	640	583	527	470	414	357	301	243	179	116	61
10	576	525	474	423	372	321	270	219	165	112	55
5	464	423	383	342	301	261	220	179	138	98	50
0	310	283	257	231	205	179	153	126	100	74	48

Table 11. Percentiles of summer average epilimnion TP concentration associated with various reductions in the summer period TP external load for the period 1991 to 2004.

Resulting Epilimnion TP Concentrations Resulting from Load Changes 1991 - 2004											
	Percent Reduction in Load										
Percentile	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
100	50.0	45.1	40.3	35.5	30.6	25.7	20.8	16.0	11.1	9.3	7.5
95	37.2	33.7	30.1	26.6	23.1	19.6	16.7	13.9	11.0	7.3	5.6
90	30.2	27.4	24.6	21.8	19.0	16.2	14.2	12.1	10.1	6.1	4.5
85	29.9	27.2	24.4	21.7	18.9	16.2	13.5	10.9	8.2	5.9	4.3
80	29.9	27.1	24.4	21.7	18.9	16.1	13.4	10.7	7.9	5.7	4.2
75	29.5	26.8	24.1	21.4	18.7	16.1	13.3	10.5	7.8	5.6	4.1
70	28.5	25.9	23.3	20.8	18.2	16.1	13.3	10.4	7.8	5.6	3.9
65	27.5	25.0	22.5	20.2	18.0	15.8	13.1	10.4	7.8	5.5	3.6
60	26.7	24.3	21.9	19.7	17.8	15.4	12.9	10.3	7.7	5.4	3.3
55	26.6	24.2	21.9	19.6	17.3	14.9	12.6	10.2	7.6	5.3	3.1
50	25.8	23.7	21.7	19.6	17.2	14.8	12.4	10.0	7.5	5.3	3.0
45	24.3	22.6	20.9	19.0	16.7	14.3	12.1	9.7	7.4	5.2	2.9
40	21.4	19.7	18.1	16.3	14.5	12.7	10.9	9.1	7.2	5.1	2.7
35	20.5	18.8	17.2	15.5	13.8	12.1	10.4	8.7	7.2	5.1	2.6
30	20.3	18.7	17.0	15.3	13.6	11.9	10.3	8.6	7.2	5.1	2.6
25	19.3	17.8	16.3	14.7	13.2	11.7	10.1	8.6	7.1	5.1	2.6
20	18.4	17.0	15.6	14.2	12.8	11.4	10.0	8.5	7.0	5.0	2.4
15	17.5	16.2	14.9	13.6	12.3	11.0	9.7	8.4	6.8	5.0	2.2
10	16.1	14.8	13.5	12.3	11.0	9.8	8.5	7.3	6.2	4.8	1.9
5	14.5	13.4	12.3	11.2	10.1	9.0	7.9	6.8	5.8	4.5	1.6
0	12.8	11.9	11.1	10.2	9.4	8.6	7.7	6.7	5.5	4.2	1.3

A 40 percent reduction in the median annual external TP load will result in a decline from 1121 kg to 702 kg. The load capacity for the internal load is set at the 1991 to 2004 annual median level predicted by the model. With a 40 percent external loading reduction, the internal load is estimated at 283 kilograms. It is assumed that the internal loading component will decline with further reductions in external TP loading and continued in lake management measures. Together, the TP load capacity to the epilimnion during the summer period is set at 985 kilograms.

Epilimnion Load Capacity (September through August) = 985 kilograms TP

External Load = 702 kilograms
Internal Load = 283 kilograms

Result of Load Reductions on Water Quality

A consideration in establishing a TP load capacity for Newman Lake is the effect that load reduction will have on water clarity. In some situations, rapid changes in water clarity, for instance, brought about by a whole lake alum treatment, can result in favorable conditions for excessive macrophyte growth, and so can result in establishing yet another water quality problem.

Figures 3 and 4 in the Applicable Criteria section, display the relationship between TP concentrations, chlorophyll (a) concentrations, and Secchi depth for Newman Lake. A 40 percent annual external TP load reduction, and decrease in summer TP concentrations to 20 ug/L, results in a shift in the median chlorophyll (a) concentrations from the current level within the 5-12 ug/L (defined by the inter-quartile range) to the 5-7 ug/L range (figure 3).

This decrease in chlorophyll (a) levels results in an increase in water clarity, as indicated by Secchi depth, of approximately 1-meter (figure 4). The current median Secchi depth of 2.0-2.5 meters will increase, with a 30 percent reduction in external TP load, to 3.0-3.5 meters.

Macrophytes ability to colonize various areas of the lake is dependent on water clarity and depth. Increased water clarity allows for a greater area for macrophyte colonization. For the majority of the lake's shoreline, the slope of the bottom sediments are relatively steep (figure 1). The exception occurs at the south-end of the lake particularly towards the outlet. Here, an increase in water clarity exposes a significantly larger portion of the bottom sediments to light resulting in an increased vulnerability to macrophyte growth. The current median Secchi depth between 2-2.5 meters, or around 8-feet would increase to around 11-feet with the loading reduction. In examining the bathymetry of the lake, the 1-meter increase in clarity provides a good compromise because further increases in clarity expose rapidly increasing areas of the lake bottom at the lake's south-end.

Load Allocations

A TP load capacity for Newman Lake has been established at 985 kg that can enter the lake from September through the following August while the summer period epilimnion concentration remaining at or below 20 ug/L, 90 percent of the time. These targets are based on long range median values. In order to meet these targets, a 40 percent reduction in the current (1991-2004) median external load is necessary.

The primary objective with establishing TP source allocations is to improve water quality to maximize the beneficial uses of the lake. There are however limits to the level of reduction possible. Total phosphorus is detectable in even the most pristine drainages. In addition, alteration to the natural landscape through, for instance, residential development, roads, agricultural, and forestry land use typically lead to increased introduction of phosphorus within surface water drainage. Recognizing that those land uses are present within the Newman Lake watershed and affect TP levels, the emphasis is not on establishing source allocations that are reflective of background loading levels. Rather, the emphasis is on setting realistic allocation targets with the understanding that through education and the implementation of best management practices, improvements can be made to reduce TP levels associated with these land uses.

Allocations are based on reductions to the major external TP load sources. Sources include surface water inflows and septic systems. While precipitation is a source of phosphorus to Newman Lake it can not be controlled and so was not considered. Surface water inflows were divided into Thompson Creek and the collective drainage exclusive of Thompson Creek within the greater Newman Lake watershed. The division here is due to the dominant influence of Thompson Creek on the lake hydrology and due to differing landscape influences on phosphorus concentrations. Thompson Creek is largely draining managed forestlands in comparison to the majority of the other surface water drainages where residential development has a greater influence on phosphorus concentrations.

Watershed Allocation

To assess the potential level of reduction that can be achieved for Thompson Creek and the other surface water drainage to Newman Lake, a reference condition is necessary. Referring to figure 13, the median TP concentration in Thompson Creek is 47 ug/L. Thompson Creek has lower variability in comparison to the other monitored surface waters. The median TP concentration for the other surface water inflows, with the exclusion of inlet 1, is 74 ug/L. The median concentration of TP observed in inlet 1 is 36 ug/L, approximately half the level observed at the other inlet locations. Inlet 1 has a lower level of residential, agricultural, and forestry related impacts that effect TP levels. The lower level of nonpoint source impacts is evident in the reduced variability in TP concentrations. For this reason, the TP concentrations observed in inlet 1 serve as a reference condition for the surface water inflow from the watershed. The phosphorus allocation associated with surface water drainage is set at a 40 percent reduction from the current estimated levels.

Thompson Creek Allocation

Because of differing size, hydrologic and geologic conditions, inlet 1 is not an appropriate reference for Thompson Creek. Liberty Creek, the main surface water inflow to Liberty Lake, located approximately 11 kilometers south of Newman Lake, shares a similar drainage size, relief, soils and geological characteristics as Thompson Creek. With the exception of alterations to its lower reach, the Liberty Creek watershed is relatively unmanaged with no road systems or industrial forestry practices. The water quality of Liberty Creek has been a focus for the Liberty Lake Sewer and Water District for a number of years with total phosphorus analysis being conducted as part of their data collection efforts. Figure 27 presents box plots of the total phosphorus concentrations observed in Liberty Creek along with those for Thompson Creek.

Median concentrations observed in Thompson Creek are almost four times greater than those observed in Liberty Creek, 47 ug/L in comparison to 13 ug/L. While it is recognized that achieving median TP concentrations as low as those observed in Liberty Creek would be difficult within the managed Thompson Creek drainage, a concentration reduction of 40 percent is manageable and consistent with the overall load capacity reduction. The load allocation for Thompson Creek is to reduce median TP concentrations, and therefore loading to Newman Lake, by 40 percent.

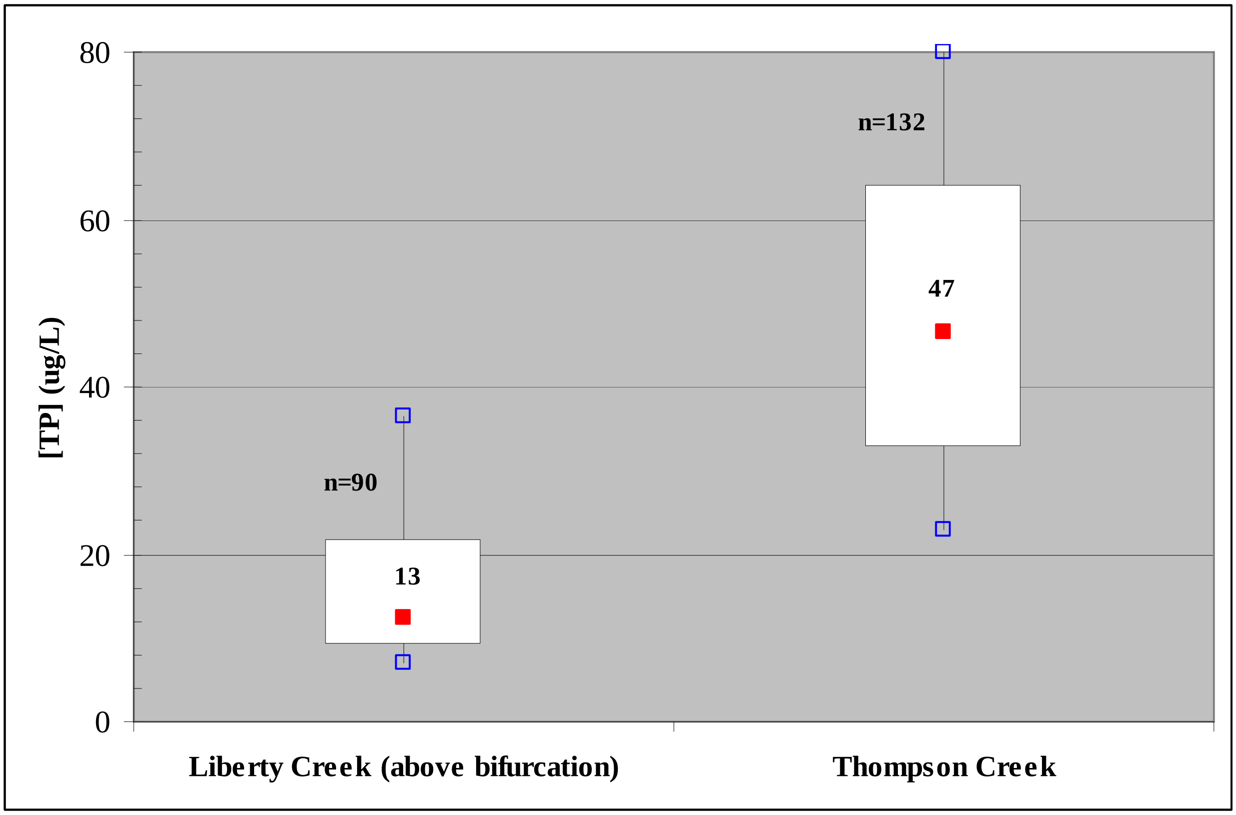

Figure 27. Box plots of total phosphorus (ug/L) observed at Liberty Creek, within the Liberty Lake watershed and Thompson Creek.

On-site Wastewater Allocation

In the Technical Analysis section of this report, it was estimated that 673 kilograms of phosphorus is associated with wastewater discharged to soils surrounding Newman Lake. Earlier studies set this estimate at 910 kg, approximately 35 percent greater (Copp, 1974). Of the 673 kg of phosphorus discharged to soils, it was estimated that 72 kg entered the lake annually (refer to table 7) indicating an approximately 90 percent retention rate. A retention rate this high while not unusual reflects a more ideal condition. Given the soil conditions surrounding the lake it is likely the overall retention rate is lower. Soils surrounding Newman Lake, the Moscow and Spokane series, because of their shallow depth to bedrock, approximately 0.8 meters, and slope combine to make the lake vulnerable to the export of phosphorus from on-site systems. While phosphorus loading associated with on-site wastewater systems was not found to be as great as that attributed to surface water sources, this and prior analyses have identified sections of the lake with a high probability for system failures (NLWPC, 1990). Based on this vulnerability and that estimates of phosphorus loading could be substantially higher from this source, the allocation is also set at a 40 percent reduction from current estimated levels.

Table 12 presents the percentile distribution of the annual external loads, 1991 to 2004, based on the 40% reductions. The load allocations, indicated by the 50th percentile, for Thompson Creek, watershed drainage, on-site systems, and precipitation are 323, 262, 43, and 76 kilograms, respectively.

Table 12. The percentile distribution of total phosphorus loads (kg) associated external sources with a 40% reduction, 1991-2004.

Percentile	Thompson Creek	Watershed	On-Site Systems	Precipitation
100	1265.7	1025.3	63.7	116.3
95	824.8	668.4	61.7	107.7
90	569.8	461.9	60.3	102.2
85	531.6	430.6	59.5	100.3
80	501.3	406.1	53.3	89.7
75	468.1	379.2	48.7	82.4
70	429.1	347.5	47.6	81.3
65	399.6	323.9	46.2	79.1
60	380.2	308.2	44.8	77.2
55	379.7	307.4	43.5	76.5
50	323.4	261.8	43.2	75.9
45	256.6	207.8	42.9	75.2
40	210.6	170.6	42.1	74.5
35	194.7	157.8	41.7	74.0
30	190.8	154.7	41.3	73.7
25	179.8	146.0	40.3	73.1
20	171.5	138.0	38.8	68.5
15	164.1	130.2	36.8	61.4
10	147.8	119.0	33.1	54.5
5	116.3	94.3	29.8	50.2
0	71.9	58.2	26.9	48.0

Margin of Safety

A margin of safety was considered throughout the analysis process of this TMDL; in the setting of the target concentration, the load capacity, and load allocations. Through this consideration, the load capacity and allocations were set to provided over a 90 percent assurance that the recommended target concentration of 20 ug/L for lakes within the Northern Rockies eco-region, the setting for Newman Lake, was met in any given summer period.

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